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The purpose of this research was to develop a model which will identify aircraft equipment items for potential reliability improvement. A model was constructed to utilize a recently compiled data base comprised of four Air Force data collection systems (G033B, D056, D041, and K051). Included in the data base are 31 active Air Force aircraft weapon systems. The model analyzes the data under three replacement policies: a. Replace on depot condemnation, b. Replace or repair at the base, and c. Replace on failure. Given the estimated investment required to improve the reliability of an item, the model will estimate the benefits that would accrue in terms of reduced support cost and increased availability. The investment and benefits are used to form an estimated return-on-investment ratio. The model was exercised on the 1650 stock class of items for the 31 mission design series aircraft. The results of the model, in terms of potential candidates for reliability improvement, were discussed with personnel assigned at the Oklahoma City Air Logistics Center.

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A COMPUTERIZED METHODOLOGY FOR THE IDENTIFICATION OF AIRCRAFT EQUIPMENT ITEMS FOR RELIABILITY IMPROVEMENT

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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June 1978

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

This thesis is the first research effort to take

CHAPTER I

INTRODUCTION

Statement of the Problem

The Air Force is concerned when reliability problems cause excessive support cost and aircraft to be grounded or unavailable for the full combat mission for which it was procured. One approach to improving weapon systems reliability is to improve the reliability of selected spares. By being selective, force wide modification expenses can be avoided.

> The portion of the Air Force's budget devoted to modifying in-inventory aircraft to improve availability, reduce aborts, and decrease equipment maintenance costs is, and always has been, quite limited [6:9].

Locating items with highest potential benefit per dollar invested is a logical and necessary prerequisite to the effective use of an austere budget (6:9).

There are several approaches to identifying high return on investment reliability improvement candidates. One approach is to act on known problems. This method is used almost completely to the exclusion of other methods. The weakness to this approach is that the known problem items may not provide the opportunity for a high return on investment. Items not on a problem item list may provide better opportunities for a higher return on investment (6:9).

A second approach to locating opportunities is to manually investigate each individual inventory item using engineering techniques. The investigation of all items in the inventory without the benefit of a systematic screening technique is impractical from a time and labor cost standpoint (6:9). A third approach is to use a computerized algorithm capable of systematically screening thousands of items to identify potential opportunities (6:9).

In light of limited Defense dollar availability, it is imperative that reliability improvement projects be chosen such that the Air Force obtains the highest possible return on investment. The problem is that there is currently no efficient method in use to select aircraft equipment reliability improvement projects from the thousands of equipment items in the inventory that will maximize return on investment.

Definitions

To provide a common frame of reference, a number of terms used frequently in this research are located in Appendix A. The list provided is not intended to be all inclusive. A more complete listing of terms can be found in A Compendium of Authenticated Logistics Terms and Definitions by Gluck (see part B of the bibliography).

Background

Today's modern weapon systems require design characteristics that are highly complex and continually stressing the state-of-the-art. Adequate testing and analysis of equipment to achieve high reliability is often hindered by time and money constraints. These factors lead to the deployment of military systems which require extensive resources to maintain and support due to failure or malfunction (10:1). For aircraft that have been in the inventory for several years, many equipment items are less reliable than the current state-of-the-art would permit (7). Historically, the Department of Defense (DOD) has recognized the need for increased equipment readiness and reduced support costs for both new and inventory aircraft.

> The reliability problem has long been recognized by defense management and design contractor and much effort has been expended over the past two decades to improve the situation. For instance, in 1952 the Advisory Group on Reliability of Electronic Equipment (AGREE) was established and made many recommendations for improvement. One such recommendation resulted in establishing a military standard for designing and conducting reliability tests (MIL-STD-781) [10:1].

The above referenced standard outlines test plans based upon exponential or Poisson distributions which are intended to be utilized for equipment testing (10:1).

Military Standard (MIL-STD)-785A, Reliability Program for System and Equipment Development and Production states that, ". . . the system's mission responsive, reliability requirements, and objectives, including minimum acceptable

values for hardware, shall be contractually specified [3:8-9]." MIL-STD-781A provides a reliability plan for test and evaluation of new weapon systems (3:10). MIL-STD-721B Military Standard Definitions of Effectiveness Terms for Reliability, Maintainability, Human Factors, and Safety, provides a common language for DOD and defense contractors by defining words and terms most frequently used in specifying effectiveness (17:1).

A Defense Science Board's Avionics Task Force Report of 1973 recommended that DOD investigate the relationships among system and subsystem reliability, availability, and life cycle costs. The office of the Director of Defense Research and Engineering (ODDR&E), acting on this recommendation, requested that the Logistics Management Institute undertake a study to investigate the relationships (10:4). One of the recommendations of this study was that reliability data be collected at the subsystem level for basic analysis and for use by future reliability growth programs (10:75). The United States Air Force (USAF) has developed data systems designed to document the activities in supporting weapon systems.

> The AFM 66-1 data base contains field information on the equipment failures of operational aircraft, causes of failure, number of maintenance actions, reasons for these actions, and average time to perform maintenance. The AFM 66-1 data base is used to identify and quantify specific reliability and maintainability problem areas [3:10].

Another system is the Increase Reliability of Operational Systems (IROS) which provides Air Force managers with necessary data to make realistic decisions (3:12-14). An inherent problem exists with these data systems.

> Resource consumption at the depot level is monitored and measured in terms of Federal Stock Class (FSC), Federal Stock Number (FSN)[1], Repair Group Category (RGC), and Mission (Weapon) Design Series (MDS), and at the base level by Work Unit Code (WUC) and organizational entity. In addition, certain items like avionics equipment are procured with Army-Navy (AN/xxx) nomenclature. Compounding the problem of multiple nomenclatures is the fact that there is no complete, official correlation between FSNs and WUCs. The current practice of purchasing items by AN designation, managing them by FSNs, and maintaining them in terms of WUCs makes it almost impossible to identify logistics support costs accurately at the item level. In general, one has to resort to allocation schemes. The Increase Reliability of Operational Systems (IROS) program provides a partial cross-reference listing between FSNs and WUCs, and at some future time may provide this important linkage [4:5].

The data base described in the next chapter contains a partial WUC/NSN cross-reference prepared by the Logistics Management Institute.

Reports on existing and developing weapon systems have studied the actual performance of weapon systems with estimated reliability figures. The 1974 RAND report on the A-7D aircraft stated:

> Avionics component reliability specifications based on bench test appeared to have little relation to the subsequent reliability of the component in an operational environment [11:V].

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[1]Federal Stock Number (FSN) is now National Stock Number (NSN).

Similarly, a 1976 report on reliability and maintainability of the A-10A stated that "Regardless of the method used to arrive at a demonstrated MTBF, the aircraft did not achieve the contractually required reliability [2:141]."

Then Deputy Assistant Secretary of Defense (Materiel Acquisition) OASD(I&L) Jacques S. Gansler commented in the April 1976 Defense Management Journal:

> An intensive program to understand and follow up on the means to significantly improve the field reliability of complex weapon systems commenced three years ago as a result of studies showing significant field reliability problems, particularly in complex weapons electronics [5:1].

Air Force Regulation (AFR) 80-5, Reliability and Maintainability Programs for Systems, Subsystems, Equipment, and Munitions, outlines the objectives, basic concepts, and policies of the Air Force Reliability and Maintainability (R&M) Program, and assigns management and development responsibilities (16:1).

Justification

The Operating and Support (O&S) costs of Air Force aircraft have been rising to the point where it is difficult to afford the quantity or quality of aircraft needed for the first rate defense of our nation (7). The increasing O&S costs were highlighted in a 1973 Air Force Flight Dynamics Laboratory report which stated:

> More than two-thirds of the national defense budget for the past six years has been required to support the existing military inventory of equipment. Cost of

> manpower and spares, which are the two main drivers in this multi-billion dollar outlay, is increasing each year [8:1].

The Air Force desires that its aircraft be reliable, ready to fight at all times, and operate with minimal support costs. While every attempt is made to initially design these features into aircraft, there is often room for improvement after an aircraft has entered the operational inventory and production has ceased (6:1). A major factor contributing to aircraft non-availability and rising O&S cost is low equipment reliability (7).

Low equipment reliability ultimately degrades military readiness. The military must be ready to respond to any world situation that threatens the security of the United States. All military forces' readiness plans are based on an assumed number of systems being in commission when needed and that those systems will perform satisfactorily. A system, as defined in Air Force Regulation 80-5 (AFR 80-5), is:

> A composite of equipment, skills, and techniques capable of performing or supporting an operational role. A complete system includes related facilities, equipment, material, services, and personnel required for its operation so it can be considered a self-sufficient unit in its intended operational and support environment [16:2].

Military weapon systems can be considered to be principle end items such as aircraft, ships, tanks, and so forth. Further, an aggregation of equipment designed to function together to perform some overall mission may be

considered a system, such as a communication system (10:6). This research effort will consider a system to be a single aircraft with all of its installed on-board equipment required to perform its assigned mission.

> An aircraft weapon system consists of a number of subsystems, which in turn may consist of major equipment and subordinate equipment called Line Removable Units (LRU) [10:6-7].

Radio Navigation, Fire Control, and Propulsion systems are aggregated collections of major components to perform specific tasks. Major components are equipment items that perform some specific function, such as radio, radar, and computer. LRUs are modules or units that are removed and replaced at the first maintenance echelon when a malfunction is detected (10:7).

"System, subsystems and LRUs are related with regard to availability, reliability, and maintainability characteristics in several ways [10:7]." System availability is the probability that an aircraft is operationally ready to perform its assigned mission at any random point in time (18:2). A system is available to perform its given mission when all subsystems are operationally ready (OR). When a subsystem fails, the cause of failure must be isolated and corrected. The time necessary to analyze the subsystem and perform proper corrective actions is the maintainability characteristic of the system (10:7). System reliability is defined as the probability that a single item which is

initially available will successfully perform its intended function without a critical failure (11:8).

> The probability that a system will be both available to initiate a mission at any random point in time and will be capable of completing the mission without a critical failure is one measurement of system effectiveness . . . [10:8-9].

System effectiveness is often defined in terms of performance characteristics such as: speed, payload, altitude, range, radar capability, and firepower accuracy. These performance characteristics are difficult to independently measure and the establishment of tradeoffs among the characteristics is even more difficult (10:2).

> Nevertheless performance requirements are established and the system is designed to meet those requirements. Given a set of system performance characteristics, the operational effectiveness of the system is not so difficult to measure. Operational effectiveness can be measured in terms of system availability and system reliability [10:2-3].

The system maintainability characteristics should be added as a measurement factor of operational effectiveness.

Reliability can be improved by increasing the length of time that a system or subsystem will operate without failure. Maintainability can be upgraded by lowering total maintenance manhours through reductions in maintenance task performance time, or by a reduction in the number of personnel required to complete a task. Improving reliability and maintainability (R&M) results in fewer failures and fewer maintenance manhours as well as a reduction in spare parts inventory requirements. These R&M improvements result in

lowering costs. A further benefit of R&M reductions is increased aircraft availability since the system spends less time in the hangar and is available to accomplish more missions. However, reliability and maintainability improvements can only be achieved at a price. Ideally the cost to improve R&M should be more than offset by lower future operating costs and/or improved operational effectiveness (1:9).

Throughout the system's life cycle, various equipment improvements are recommended to upgrade reliability and maintainability characteristics (1:3).

> The problem for program managers lies in deciding whether the cost of improving the aircraft will be sufficiently offset by the reduction in expenditures for maintenance that are expected to result if the improvements are made [1:3].

Rigorous analytical techniques for R&M improvements have not always been utilized in the past because they either were too complicated to use or were not available (1:3).

Reference was made previously to the IROS system which is a currently utilized method

> . . . to identify those subsystems, components, and items of equipment which are disproportionate resource consumers, high contributors to system non-availability or potential safety problems based on their reliability or maintainability performances [14:10-1].

The primary products of the IROS program are rankings of items by their Logistic-Support-Cost (LSC) presented in several formats (LSC, WUC, NSN, etc.). The basic contention is that those items high on the LSC list are more deserving

of attention than those lower on the list. This approach is a direct, simple, and easily understood approach to the identification of items which are consuming an enormous amount of support dollars.

It is the contention of the researchers that the IROS-Logistic-Support-Cost (IROS-LSC) ranking approach can be supplemented to account for more factors bearing on the reliability improvement candidate identification problem. First the IROS-LSC ranking approach does not include system availability benefits resulting from improved reliability (7). This availability factor could be added to estimate the reliability induced system degradation. This degradation is composed of the remaining life support cost for the equipment item in question and the dollar value of the aircraft which is not available to perform its intended mission due to the unsatisfactory reliability of the item.

A second deficiency with the IROS-LSC is a lack of an estimation of investment required to improve the reliability of identified items. As might be expected, the most expensive items such as jet engines, and inertial navigation systems are congregated at the top of the IROS-LSC list. It follows that significant reliability improvement in these complex, expensive items is extremely costly. Conversely a mundane and inexpensive item, such as a $100 hydraulic valve, will rank quite low on the IROS-LSC listing even if the

annual support cost is quite high in relation to the $100 unit price.

The IROS-LSC approach could be strengthened by considering availability benefits as well as support costs. These factors when coupled with an estimate of the investment required to achieve improved system reliability, would result in a model which is an efficient and responsive vehicle for assisting management in the identification of reliability improvement candidates.

Research Objective

Where product improvement efforts have been continuously undertaken, significant reductions in failure or removal rates have resulted (1:7).

> An integral component of any product improvement program is a method for quickly and conclusively determining the most beneficial changes that could be incorporated into in-service aircraft [1:7].

It would be highly desirable to investigate all aircraft equipment items for reliability improvement. Using engineering estimation techniques, the investigation of all items is cost prohibitive. One selection technique that could be employed is to select aircraft spares at random for reliability improvement investigation. Using this approach the researchers believe that the yield of high potential return on investment items versus low potential return on investment items would be unsatisfactory. Furthermore, it

is highly possible that only a small segment of the population of items would be investigated.

In light of the above considerations, the research objectives were to develop, apply, and evaluate a computerized screening methodology which could identify aircraft equipment items for reliability improvement. These same items, if their reliability were improved, would have a potentially high return on investment if introduced as spares on a normal attribution or replacement-on-failure basis.

Research Hypothesis

It was hypothesized that the computerized screening model developed in this research is a more effective discerner of identifying equipment item candidates for reliability improvement programs than the present approaches employed.

Scope

In the past, analysis of logistics data has been performed on many systems parameters, and on many different aircraft. Nevertheless, the studies have usually been restricted to a few parameters and aircraft types due to data base limitations. Recently, however, a data base was formulated that merged data from four major data systems, and provides a partial work unit code to national stock number (WUC/NSN) cross-reference. The data base contains information concerning thirty-one major series of Air Force

aircraft. This thesis is the first research effort to take advantage of this data base which is described in Chapter II.

The scope of this research is to utilize this data base to develop, apply, and evaluate a computerized methodology to identify potential high benefit to investment ratio aircraft spares for reliability improvement.

Limitations

The data base is limited to thirty-one Air Force aircraft weapon systems. The data are historical data for the period October 1976 through September 1977. The data sources are from existing Air Force Data systems. These sources (described further in Chapter II) contain information related to equipment deficiencies and system operational statistics. Causes of system downtime such as preflight and post flight inspections that are not related to specific equipment items are not included in the analysis. Excluded from the analysis is improved performance such as increasing bombing accuracy. The emphasis is placed on increasing weapon system availability, decreasing mission aborts and reducing operating and support costs. An assumption is made that the benefits derived from the improvement of one equipment item will not be reduced by degrading the performance and availability of other items in the system.

While the model was developed for all types of equipments, the actual evaluation of the model was restricted to Federal Stock Class (FSC) 1650, which consists of items such as: valves, actuators, and constant speed drives. This narrowed the scope of the research effort so that a detailed analysis of the computerized model could be performed.

Chapter Synopsis

In this chapter we have presented a statement of the problem, background and justification for the study, identified the scope and direction of the research, and stated the limitations. The next chapter presents the methodology used in the research effort. A detailed description of the mathematical model used in the research is provided in Chapter III. Chapter IV provides an analysis of the model application. Finally, Chapter V presents conclusions and recommendations.

CHAPTER II

METHODOLOGY

Introduction

Improving the reliabilities of equipments on aircraft currently in the inventory can have several beneficial effects. Improved reliability can result in: improved mission accomplishment, fewer aborts and/or accidents, increased availability, and reduced maintenance cost at both the base and depot levels.

Methods of Introducing Improved Equipment

There are several ways to introduce improved reliability equipment into the active inventory. Some of the replacement policies are: (a) Force Modification (Force Mod), (b) Replace on Condemnation (ROC), (c) Replace or Repair at Base (RORAB), (d) Replace on Failure (ROF).

Force modification. This method of introducing equipment would replace existing equipment without regard to the condition of the existing equipment. The actual replacement process would either be accomplished at the base or depot level depending upon the complexity of the maintenance actions required to accomplish the task. This method is expensive for several reasons. It would replace serviceable

items that would have considerable life remaining. It requires large capital outlays to completely retrofit an entire fleet of aircraft over a relatively short period of time. Furthermore, it adversely effects aircraft availability since the aircraft must be grounded to complete the modification.

Replace on condemnation. This method of adding improved spares to the inventory is to replace the defective item when it is condemned. When an item is condemned either at the base or depot level, a new improved spare is entered into the inventory. This method utilizes the normal useful life of the old spare and enters the improved spares into the inventory at a slower rate than the other methods. Initial capital investment would tend to be less and the total investment could be amortized over a longer time period.

Replace or repair at the base. This method of introducing improved items into inventory is somewhat accelerated compared with the replace on condemnation policy. Upon removal of the item from the aircraft, it is bench checked to isolate the reason for failure. If it is determined that the item can be repaired at the base, this action is accomplished and the item returned to service. If on the other hand, the item is beyond the repair capability of the base, and it is a depot condemnation/repair item, it would be condemned at the base in lieu of returning it to the depot for

appropriate action. The new improved reliability item would then be installed on the aircraft.

Replace on failure. The fourth method of adding improved spares to the inventory is to replace the defective item on failure. When an item malfunctions, it would be removed and replaced with the improved reliability model instead of being repaired and reinstalled. This replacement method ignores the possible remaining life of the old spare but it does get the improved item installed into the weapon system at a fairly rapid rate.

Of the four replacement policies described above, the force mod case will not be further investigated. This case is a commonly used method for quickly replacing defective safety-related components. This method of replacement is also used to modify an existing aircraft to perform a specific mission or to upgrade mission capability. The intent of this research is to provide a means of identifying equipment items for reliability improvement that are consuming an inordinate amount of maintenance manhours and/or spares due to low reliability. The three remaining replacement policies are an integral part of the model (described in Chapter III). The model computes the potential return on investment under each policy. It then identifies that policy which provides the highest return on reliability improvement dollar investment.

As a part of the research methodology, the researchers investigated current Air Logistics Center's (ALC) approaches to the identification of equipment for improvement. The following section describes the ALC's approaches.

Current Approach

The current approaches for the identification of items for reliability improvement presented herein are not meant to be all inclusive. These are some of the ways in which problem items are identified based on a visit and a telephone interview with personnel from Oklahoma City Air Logistics Center (OCALC), Tinker Air Force Base, Oklahoma.

Figure 2.1 pictorially depicts the flow of the problem identification process. This process is described as follows. The information is generated from several sources. Some of which are shown in the figure. Field generated data comes from Materiel Deficiency Reports (MDR), and base level maintenance activities. Other sources of problem item information include: Major Commands, System Managers, and Item Managers. Potential problems and trends are also identified by overhaul agencies. Demand data from the D041 supply system is analyzed quarterly. The AFM 66-1 data provides deficiency packages for item analysis.

Information from these sources identified above flow to the Equipment Specialists (ES). The ES uses this information to generate detailed analyses. The results of the

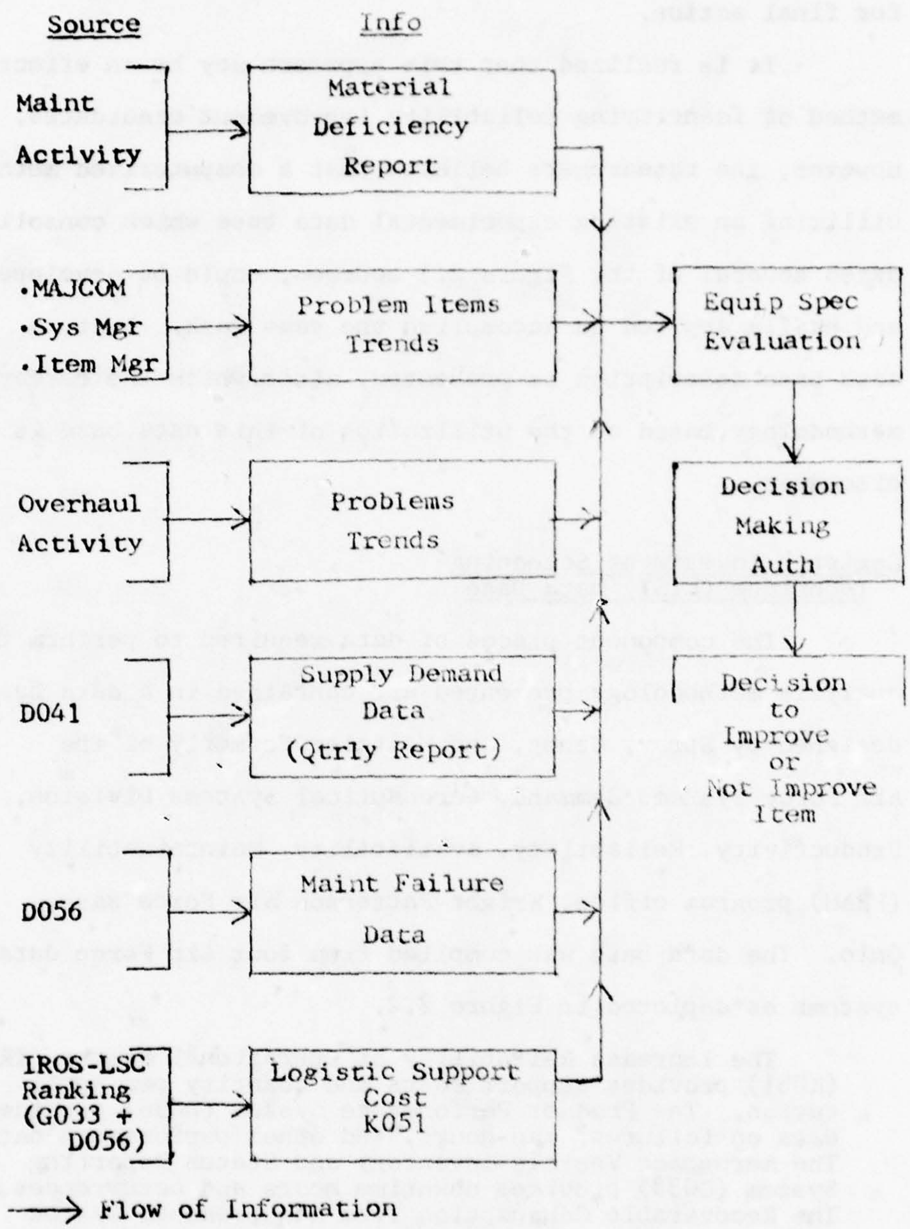

Figure 2.1. Current Approach

analyses are reviewed and forwarded to appropriate levels for final action.

It is realized that this approach may be an effective method of identifying reliability improvement candidates. However, the researchers believed that a computerized method utilizing an existing experimental data base which consolidates several of the Figure 2.1 sources, could be developed and easily applied to accomplish the same task. Next, a data base description is presented, after which the research methodology based on the utilization of this data base is discussed.

Logistic Investment Screening Technique (LIST) Data Base

The component pieces of data required to perform the analysis methodology presented are contained in a data base designed by Spray, Genet, and Meitzler formerly of the Air Force Systems Command, Aeronautical Systems Division, Productivity, Reliability, Availability, Maintainability (PRAM) program office, Wright-Patterson Air Force Base, Ohio. The data base was compiled from four Air Force data systems as depicted in Figure 2.2.

> The Increase Reliability of Operational System (IROS) (K051) provides support costs and quantity per application. The Product Performance System (D056) provides data on failures, man-hours, and other performance data. The Aerospace Vehicle Inventory and Status Reporting System (G033) provides downtime hours and occurrences. The Recoverable Consumption Item Requirements System (D041) provides unit prices, item manager identification, and other data. Since K051 and G033 are geared to work

unit codes (WUC) and D041 is by master stock number (MSN), a WUC/MSN cross reference was required [6:11-12]. The Logistics Management Institute developed such a cross reference which was modified for inclusion in the data base.

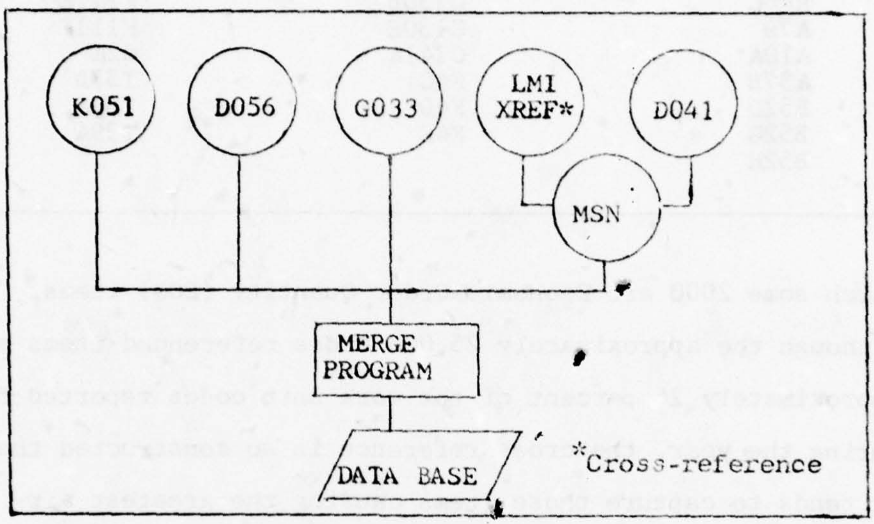

Figure 2.2. LIST Data Sources (6:11)

The data from the four separate systems were reformatted, edited, and merged into three computer tapes for use in analysis. The information on the merged tapes is for the period October 1976 to September 1977. The three data tapes contain data on thirty-one United States Air Force aircraft (Table 2.1) and 127,577 authorized Work Unit Codes (WUC). Of these WUCs, 93,293 had action reported against them during the year. Of these 93,293 WUCs only 24,686 are contained in the WUC/NSN cross reference, of

Table 2.1

LIST Aircraft

FB111A	EB57E	F15A
HC130A	C5A	F106A
KC135A	C9A	F111A
OV10	C130A	F111D
RF4C	C130B	F111E
A7D	C130E	F111F
A10A	C141A	O2A
A37B	F4C	T37B
B52D	F4D	T38A
B52G	F4E	T39A
B52H		

which some 2000 are Economic Order Quantity (EOQ) items. Although the approximately 25,000 cross referenced items are approximately 26 percent of the work unit codes reported on during the year, the cross reference is so constructed that it tends to capture those items causing the greatest aircraft availability degradation. Previous LIST analysis showed that the cross referenced items accounted for over one-half of the total aircraft availability degradation (6).

Research Approach

The research approach, as shown in Figure 2.3, was to develop a model capable of utilizing the LIST data base to identify aircraft equipment items for reliability improvement. A detailed development of the mathematical model is the subject of Chapter III. The model was computerized (FORTRAN programming language) and a listing of the program

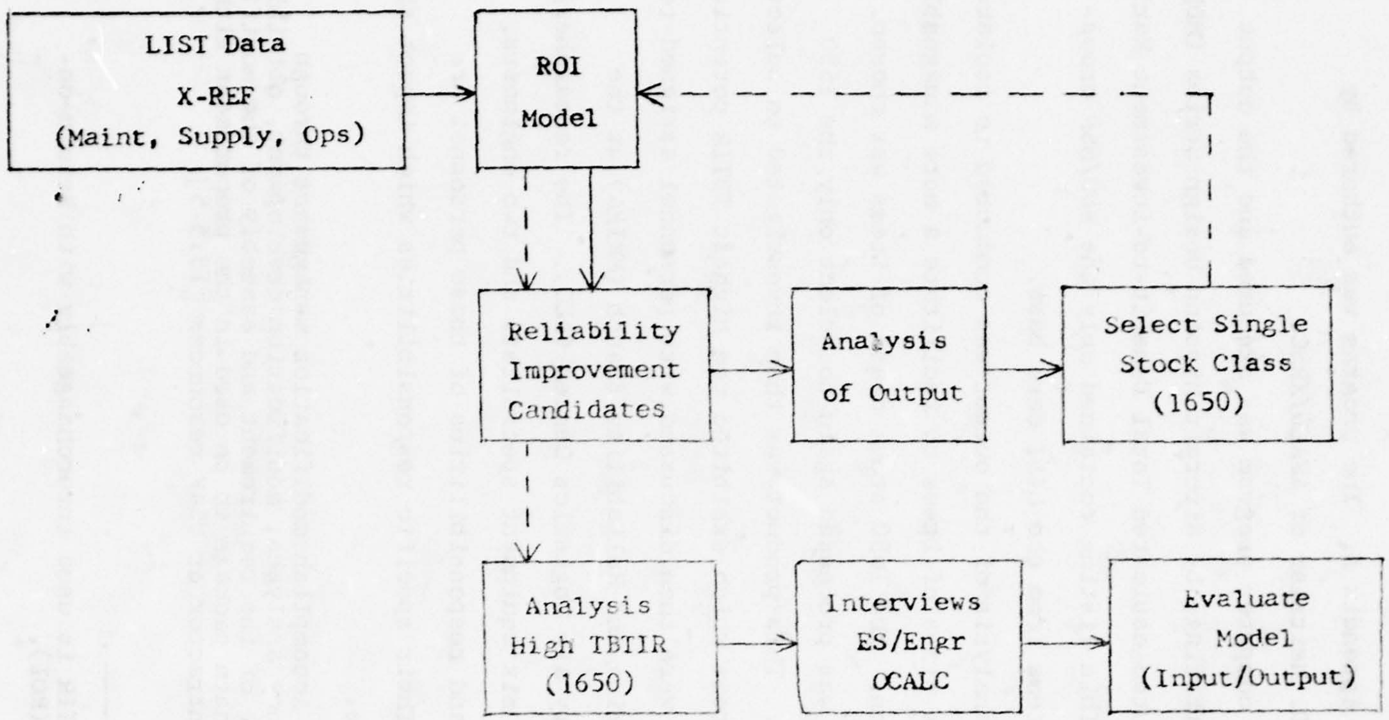

Figure 2.3. Research Approach

is shown in Appendix B. The program was authored by Mr. Thomas D. Meitzler of AFALD/XRSC.

The computer program was executed and the output provided a listing, by aircraft Mission Design Series (MDS), of the computed estimated Total Benefit-to-Investment Ratios (TBTIR).[2] This listing contained only the WUC/NSN cross-reference items from the LIST data base.

An analysis of the output was conducted to isolate a single stock class of items to facilitate a more manageable investigation. The 1650 stock class of items was chosen. The program was processed again to select only the 1650 stock class. This product was then investigated to select a sample of items which exhibited the highest TBTIR potential. These items were then discussed with personnel assigned to the Engineering and Reliability Branch (MMIRA) at the Oklahoma City Air Logistics Center (ALC). The researchers interviewed six equipment specialists and two engineers. The duties and responsibilities of these personnel are numerous. Their specific responsibilities which impact this research are:

> (1) Accomplish modification management through deficiency analyses, modification development, obtaining approval of the requirement and assembly of the modification data package to be used in the procurement either from contractor or USAF resources [13:5-5].

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[2] TBTIR is used interchangeably with Return-on-Investment (ROI).

(2) Identify and submit reports on items having a low reliability and poor performance; compute logistics support costs due to substandard items; implement corrective actions where justified by reliability and performance increases and cost amortization time [13:5-5].

The information provided by the branch personnel was used to aid in the evaluation of the model and the LIST data base.

Summary

This chapter presented four methods of introducing improved equipment into the active aircraft inventory. These were: (a) Force Modification; (b) Replace on Condemnation; (c) Replace or Repair at Base; (d) Replace on Failure. The mathematical model presented in the next chapter evaluates data under (b), (c), and (d) to provide an estimated Total Benefit-to-Investment Ratio. A description of the current approaches of identifying candidate improvement items was presented. The data source for this research was the Logistic Investment Screening Technique (LIST) which was also described in this chapter. Finally, the research approach which was employed to utilize the LIST data and accomplish the research objectives was described.

CHAPTER III

RETURN-ON-INVESTMENT MATHEMATICAL MODEL

Introduction

The purpose of this chapter is to describe the Return-on-Investment Model through which the LIST data was processed to ascertain the potential return-on-investment the Air Force might realize if the aircraft equipment items are improved. The model was developed under the guidance of Mr. Russell M. Genet of the Air Force Acquisition Logistics Division, Air Force Logistics Command (AFLC/AFALD) at Wright-Patterson Air Force Base, Ohio.

Notation

Three subscripts are used throughout the model development. These subscripts are k, s, and e. The subscript k denotes a fixed constant parameter while s denotes a parameter that varies from one system to the next. The e subscript denotes a parameter that may vary from one equipment item to the next on a given aircraft. Two functional notations are utilized. One denotes a parameter which is a function of time (t), the other denotes an integral evaluated between $t = 0$ and $t = T$ and is denoted (T).

As a first step in constructing the model, it is necessary to consider an equipment item "e", an aircraft type "s", and establish what the remaining life demands would be. It is also necessary to calculate the steady state annual flying hours per aircraft. The equation is:

$$AFHPA_s = \frac{AFFH_s}{INV_s} \tag{1}$$

where:

$AFHPA_s$ is the annual flying hours per aircraft.

$AFFH_s$ is the annual fleet flying hours.

INV_s is the active inventory.

The assumptions that must be made in this calculation are that $AFFH_s$ and INV_s have reached a steady state value and that they will remain unchanged over the time period under investigation. Since this time period is often the remaining aircraft life, and flying hours tend to taper off at the end of the life (phase out), this assumption is not always valid. First, the ratio of $AFFH_s/INV_s$ should remain fairly constant as the factors tend to diminish together. The effective remaining life, ERL_s is defined so that:

$$ERL_s = \int_0^{ARL_s} \frac{INV_s(t)dt}{INV_s} \tag{2}$$

where:

ERL_s is the effective remaining life.

INV_s is the steady state inventory over the main portion of the life.

ARL_s is the "actual" remaining life.

The result of the above is to square off the tail of the graph while retaining the same total remaining life flying hours, i.e., the area bounded by the points ABO equals the area bounded by ADCO (see Figure 3.1).

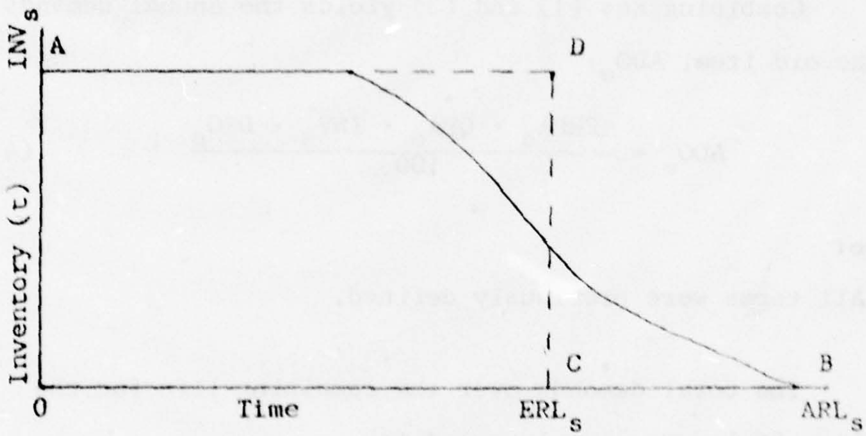

Figure 3.1. Effective vs. Actual Remaining Life

The next step is to define the demand rate of the old equipment. The D041 supply computation program equation is:

$$DRO_e = \frac{ADO_e}{\frac{AFFH_s \cdot QPA_e}{100}} \qquad (3)$$

where:

DRO_e is the annual demand rate of the old item.

ADO_e is the annual demands for the old item.

$AFFH_s$ is the annual fleet flying hours.

QPA_e is the quantity per application.

NOTE: The product, $AFFH_s \cdot QPA_e$ gives the equipment flying hours. Thus the demand rate, DRO_e as defined by the D041 program is the annual demands per 100 equipment flying hours.

Combining Eqs (1) and (3) yields the annual demands of the old item, ADO_e:

$$ADO_e = \frac{AFHPA_s \cdot QPA_e \cdot INV_s \cdot DRO_e}{100} \tag{4}$$

where:

All terms were previously defined.

The total demands over the remaining life for the old item if it were not improved is:

$$TDO_e = ADO_e \cdot ERL_s \tag{5}$$

where:

TDO_e is the total demands for the old item.

ADO_e is the annual demands for the old item.

ERL_s is the effective remaining life.

Demand Time Constant

The replacement policies effect how quickly, in calendar time, the old item is replaced by the new improved reliability item. The replacement time factor is also effected by the reliability of the old item, such as the assumed failure distribution, and the amount of flying hours accumulated.

In this analysis it is assumed that the failure distribution of all items are of a "constant hazard" or "exponential" form. This assumption is probably valid for electronic type equipment, although it is less so for mechanical types of components that often exhibit a wearout, non-constant, failure mode. While it would be desirable to wear out type distributions for mechanical items (such as the Weibul distribution), the data to estimate the parameters are not contained in the data base, and in fact are not generally available except on very expensive serial numbered items with elapsed time indicators (ETI), such as jet engines and inertial navigation units.

The first step in calculating the demand time constant is to determine the failure (hence demand) rate of the old item. As time progresses, fewer unimproved items will remain in the inventory, and in the limit as t approaches infinity ($t \rightarrow \infty$), there will be none at all. It would be expected that the failure (demand) rate of the old item would correspondingly decrease over time. If this

decrease is exponential, then:

$$ADO_e(t) = K_e \cdot e^{-t/TC_e} \qquad (6)$$

where:

$ADO_e(t)$ is the annual demands (failure rate) of the old item.

K_e is a coefficient derived below.

TC_e is the time constant, derived below.

when:

$t = \emptyset$, $e^{-t/TC} = 1.\emptyset$, ADO(t) will then equal the annual demand rate if no improved item had been introduced (see Eq (4)).

Thus:

$$K_e = \frac{AFHPA_s \cdot QPA_e \cdot INV_s \cdot DRO_e}{100} \qquad (7)$$

For the replacement policy of replacing all old items with new items upon failure of the old items, the time constant is:

$$TC_e = \frac{MFHBD_e}{AFHPA_s} \qquad (8)$$

where:

$1C_e$ is the time constant.

$MFHBD_e$ is the mean equipment flying hours between demand.

$AFHPA_s$ is the annual flying hours per aircraft.

The mean equipment flying hours between demand is:

$$MFHBD_e = \frac{AFFH_s}{ADO_e} \qquad (9)$$

where:

$MFHBD_e$ is the mean equipment flying hours between demand.

$AFFH_s$ is the annual fleet flying hours.

ADO_e is the annual demands of the old item (no new items introduced).

Substituting $AFHPA_s \cdot INV_s$ for $AFFH_s$, Eq (4) for ADO_e, and simplifying yields:

$$MFHBD_e = \frac{100}{DRO_e \cdot QPA_e} \qquad (10)$$

For the replace on condemnation and the replace in lieu of depot repair policies, the time constant will increase because of the increased time to replace the old items. For these policies, only a fraction of the items are replaced. Thus a replacement fraction must be calculated for each policy. This calculation will be developed in the next section.

Utilizing Eqs (6) through (10), it can now be stated that the annual demand (failure) rate of the old item is:

$$ADO_e(t) = DRO_e \cdot \frac{AFHPA_s}{100} \cdot QPA_e \cdot INV_s \cdot e^{-t/TC_e} \qquad (11)$$

and:

$$TC_e = \frac{\frac{MFHBD_e}{RF_e}}{AFHPA_s} \tag{12}$$

where:

ADO_e is the annual demands for the old items.

DRO_e is the annual demand rate of the old item.

$AFHPA_s$ is the annual flying hours per aircraft.

QPA_e is the quantity per application.

INV_s is the active inventory.

TC_e is the time constant.

$MFHBD_e$ is the mean equipment flying hours between demand.

RF_e is the replacement fraction to be developed in the next section.

The number of old equipment items installed in the aircraft inventory at any point in time is:

$$NOEI_e(t) = QPA_e INV_s\, e^{-t/TC_e} \tag{13}$$

where:

$NOEI_e$ is the number of old equipment items.

QPA_e is the quantity per application.

INV_s is the active inventory.

TC_e is the time constant.

Since the total number of equipment items (old and new) must at all times be $QPA_e \cdot INV_s$, then the number of new equipment items must be at any time t:

$$NNEI_e = QPA_e \cdot INV_s - QPA_e \cdot INV_s \cdot e^{-t/TC_e}$$

$$= QPA_e \cdot INV_s \left(1 - e^{-t/TC_e}\right) \qquad (14)$$

where:

$NNEI_e$ is the number of new equipment items; other factors defined above.

Using reasoning similar to that for Eq (11), the annual demand rate for the new item is:

$$ADN_e(t) = DRN_e \cdot AFHPA_s \cdot QPA_e \cdot INV_s \left(1 - e^{-t/TC_e}\right) \qquad (15)$$

where:

ADN_e is the annual demand rate for the new items.

DRN_e is the demand rate for the new items.

$AFHPA_s$, QPA_e, INV_s and TC_e as previously defined.

Replacement Fraction

To calculate the replacement fractions for each of the replacement policies, it is helpful to consider the flow of spares through the repair/condemnation cycle. The flow process is depicted in Figure 3.2.

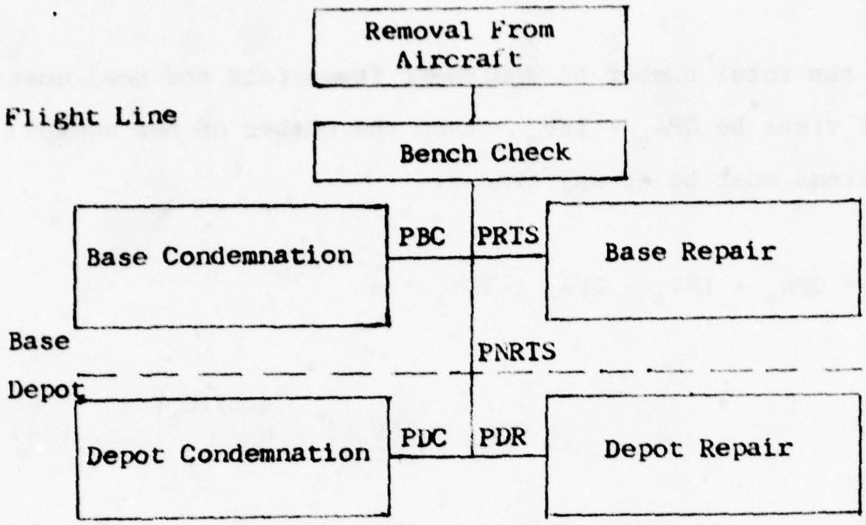

Figure 3.2. Flow Diagram

Defective equipment items are removed from the aircraft on the flight line when the malfunction is detected by maintenance personnel or the malfunction is properly annotated on maintenance forms by aircrew personnel. At the base level the items can be processed in one of three ways. First, the defective equipment can be repaired in the base maintenance shop and returned either to the aircraft or to supply as appropriate. Secondly, depending on the Expendability, Recoverability, Repairability, Category Code (ERRC) which determines if the base has condemnation authority for the item (ERRC XB or XF) and the item is determined to be beyond repair, it can be condemned and a new item drawn from supply. Third, the spare can be shipped to the depot (ERRC XD) for either repair or condemnation as appropriate.

The ERRC is a code, the first position of which is the expendability position; an 'X' indicates expendable and indicates that the item looses its identity in use or is consumed in use. A first position of 'N' indicates non-expendable, items do not loose their identity in use. The second position can be a 'B', 'F' or 'D' and indicates the highest level of repair/condemnation authority; a 'B' indicates base or user level, 'F' means field level (i.e., base maintenance shop), and a 'D' means depot level authority. The third position of the ERRC at one time had a dollar value meaning but has in recent years lost its importance. If an item has an ERRC of XB3 it is expendable and can be condemned/repaired at base (user) level. An item with ERRC XF3 is expendable and repaired/condemned at field level (i.e., the maintenance shop on base with repair/condemnation capability). An XD2 item is expendable and is repairable at base, field and depot levels but may only be condemned at the depot level. An NF2 item is non-expendable and base or field repairable and field condemnable.

The figure also depicts the percentages of base/depot condemnation rates and base/depot repair rates. Thus for the base:

$$PBC_e + PNRTS_e + PRTS_e = 100 \qquad (16)$$

where:

PBC$_e$ is the percent base condemnation.

PNRTS$_e$ is the percent not repairable this station (base).

PRTS$_e$ is the percent repairable this station (at the base).

Since PRTS$_e$ is not an element of the LIST data base, it must be calculated thusly:

$$PRTS_e = 100 - PBC_e - PNRTS_e \qquad (17)$$

For the depot branching depicted in Figure 3.2, the percentages are:

$$PDC_e + PDR_e = 100 \qquad (18)$$

where:

PDC$_e$ is the percent depot condemnation.

PDR$_e$ is the percent depot repair.

Since PDR$_e$ is not contained in the data base, it must be calculated.

$$PDR_e = 100 - PDC_e \qquad (19)$$

The replacement fraction for each replacement policy can now be defined. It is the fraction of items replaced per removal from the aircraft.

In the natural attrition case, replacement is made only through base or depot level condemnation action. This

fraction is:

$$RF(NA) = \frac{PBC}{100} + \frac{PNRTS}{100} \cdot \frac{PDC}{100} \qquad (20)$$

where:

RF(NA) is the replacement fraction given a replacement policy of natural attrition and the other terms as previously defined.

If the natural attrition rate is quickened by also replacing the old item when it would have normally received depot repair, then the replacement fraction is:

$$RF(CODR) = \frac{PBC}{100} + \frac{PNRTS}{100} \qquad (21)$$

where:

RF(CODR) is the replacement fraction for a replacement policy of condemnation or depot repair, other terms as previously defined.

Finally, for the replace on failure policy, all items are replaced on failure without regard for normal repair/condemnation processing. Thus, the replacement factor for replace on failure is:

$$RF(ROF) = 1.0 \qquad (22)$$

Total Demands

Having previously established the annual demand rates as a function of time, t, for the old and new (improved

reliability) spares (see Eqs (11) and (15)), total demands can now be calculated. The total demands over some time period are simply the integral of the annual demand rate. Thus the total demands for the old and new items as t goes from Ø to T are respectively:

$$TDO_e(T) = \int_0^T ADO_e(t)dt \tag{23}$$

and

$$TDN_e(T) = \int_0^T ADN_e(t)dt \tag{24}$$

where:

$TDO_e(T)$ is the total demands for the old item in time period T.

$TDN_e(T)$ is the total demands for the new item in time period T.

$ADO_e(t)$ is the annual demands for the old item in time period t.

$ADN_e(t)$ is the annual demands for the new item in time period t.

Substituting the functions for ADO_e and ADN_e from Eqs (11) and (15) respectively, results in, after performing the indicated integration:

$$TDO_e(T) = \frac{DRO_e}{100} \cdot AFHPA_s \cdot INV_s \cdot QPA_e \cdot TC_e \left(1 - e^{-T/TC_e}\right) \tag{25}$$

simplified:

$$TDO_e(T) = \frac{DRO_e}{100} \cdot INV_s \cdot QPA_e \cdot \frac{1}{RF}\left(1 - e^{-T/TC_e}\right) \qquad (26)$$

where:

$TDO_e(T)$ is the total demands for the old item in time period T.

DRO_e is the annual demand rate of the old item.

$AFHPA_s$ is the annual flying hours per aircraft.

INV_s is the active inventory.

QPA_e is the quantity per application.

TC_e is the time constant.

RF_e is the replacement fraction.

and:

$$TDN_e(T) = \frac{DRN_e}{100} \cdot AFHPA_s \cdot QPA_e \cdot INV_s\left[T + TC_e\left(e^{-T/TC_e}\right)\right] \qquad (27)$$

simplifying:

$$TDN_e(T) = \frac{DRN_e}{100} AFFH_s \cdot QPA_e \cdot \left[T + TC_e\left(e^{-T/TC_e} - 1\right)\right] \qquad (28)$$

where:

$TDN_e(T)$ is the total demands for the new item in time period T.

DRN_e is the demand rate of the new item.

$AFHPA_s$ is the annual flying hours per aircraft.

$AFFH_s$ is the annual fleet flying hours, other items recently defined.

Cost per Demand

Knowing the total demands, the cost savings can be calculated if the average cost per demand for the new and old items is known. The average cost per demand for the new item does not vary from one replacement policy to the next since a policy other than natural attrition is applied only to the old items to accelerate replacement. Thus the aircraft cost per demand for the old item depends on the replacement policy, therefore it is necessary to develop an equation for each policy.

Before the equations are developed, it is necessary to develop the basic cost for each possible action. These possible actions are depicted in Figure 3.2 and are summarized here for continuity. The possible actions are: (1) Base condemnation; (2) Base repair; (3) Depot condemnation; and (4) Depot repair.

The condemnation case is the easiest to formulate, since the condemned item is replaced with the new item at a cost of its unit price, thus:

$$CPBC_e = CPDC_e = UPN_e \tag{29}$$

where:

$CPBC_e$ is the cost per base condemnation.

$CPDC_e$ is the cost per depot condemnation.

UPN_e is the unit price of the new item.

Depot repairs are presented in an equally simplistic manner since the cost per average repair is known, thus:

$$CPDR_e = URC_e \tag{30}$$

where:

$CPDR_e$ is the cost per depot repair.

URC_e is the unit repair cost for the new or old item as appropriate.

For flight line removal, (repair, reinstallation, etc.) the total annual unscheduled maintenance manhours and the labor rate factors are known--D056:

$$CPAR = \frac{\text{ANNUAL COST}_e}{\text{ANNUAL DEMANDS}_e} = \frac{UMMH_e \cdot BLR_k}{DRO_e} \tag{31}$$

where:

CPAR is the cost per flight line action.

$UMMH_e$ is the annual unscheduled maintenance manhours.

BLR_k is the base labor rate ($14.00/hour) (9:IV-6).

DRO_e is the annual demands (see Eq (3)).

Similar reasoning can be applied to the base repair case, thus:

$$CPBR_e = \frac{\text{ANNUAL COST}_e}{\text{ANNUAL DEMANDS}_e} = \frac{SRH_e \; BLR_k}{DRO_e \; \frac{PRTS}{100}} \tag{32}$$

where:

$CPBR_e$ is the average cost per base repair.

SRH_e is the annual shop repair hours.

PRTS is percent repaired this station (at the base).

All other terms recently identified.

The average cost per demand for each of the three replacement policies then is computed by multiplying the cost of each action by the fraction of time that particular action occurs on the average.

Having established the cost for each action, and having previously established the flow of items for each replacement policy, it is now possible to combine the two to obtain an average cost per demand for each function.

The equation for flight line cost per demand is:

$$CPDFL_e = CPFLA_e \cdot FLOW_e = CPFLA_e \cdot 1.0 \tag{33}$$

where:

$CPDFL_e$ is the cost per demand, flight line.

$CPFLA_e$ is the cost per flight line action.

$FLOW_e$ is the fraction of units receiving this action (1.0 in this case).

The cost of base condemnation per demand can be determined by:

$$CBDBC_e = CPBC_e \cdot \frac{PBC_e}{100} = UPN_e \cdot \frac{PBC_e}{100} \qquad (34)$$

where:

$CBDBC_e$ is the cost per demand, base condemnation.

$CPBC_e$ is the cost per base condemnation.

PBC_e is the percent base condemnation.

UPN_e is the unit price of the new item.

The cost per demand for base repair is:

$$CPDBR_e = CPDBR_e \frac{PRTS}{100} = \frac{SRH_e \; BLR_k}{DRO_e \frac{PRTS}{100}} = \frac{SRH_e \; BLR_k}{DRO_e} \qquad (35)$$

where:

$CPDBR_e$ is the cost per demand, base repair.

PRTS is the percent repaired this station.

SRH_e is the annual shop repair hours.

BLR_k is the base labor rate.

DRO_e is the annual demands.

The cost per demand for depot condemnation is:

$$CPDDC_e = CPDC_e \frac{PNRTS_e}{100} \cdot \frac{PDC_e}{100} = UPN_e \cdot \frac{PNRTS_e}{100} \cdot \frac{PDC_e}{100} \qquad (36)$$

where:

$CPDDC_e$ is the cost per demand, depot condemnation.

CPDC is the cost per depot condemnation.

PNRTS is the percent not repaired this station.

PDC_e is the percent depot condemnation.

UPN_e is the unit price of the new item.

The cost per demand for the depot repair is:

$$CPDDR_e = CPDR_e \cdot \frac{PNRTS_e}{100} \cdot \left(1 - \frac{PDC_e}{100}\right)$$

$$= URC_e \cdot \frac{PNRTS_e}{100} \cdot \left(1 - \frac{PDC_e}{100}\right) \quad (37)$$

where:

$CPDDR_e$ is the cost per demand, depot repair.

$CPDR_e$ is the cost per depot repair.

URC_e is the unit repair cost, other terms recently defined.

For all new items, since they are not affected by replacement policies, the average cost per demand is:

$$CPDN_e = CPDFL_e + CPDBC_e + CPDBR_e + CPDDC_e + CPDDR_e \quad (38)$$

where:

$CPDN_e$ is the average cost per demand for a new item.

$CPDFL_e$ is the cost per demand, flight line.

$CPDBC_e$ is the cost per demand, base condemnation.

$CPDBR_e$ is the cost per demand, base repair.

$CPDDC_e$ is the cost per demand, depot condemnation.

$CPDDR_e$ is the cost per demand, depot repair.

The average cost per demand for the old item depends on the replacement policy. The three cost equations for the alternative replacement policies follow:

For natural attrition, the formula is:

$$CPDO_e = CPDFL_e + CPDBC_e + CPDBR_e + CPDDC_e + CPDDR_e \quad (39)$$

where:

$CPDO_e$ is the cost per average demand for the old item, other terms defined above.

For the natural attrition plus condemnation of items that would have received depot repair, the equation is:

$$CPDO_e = CPDFL_e + CPDBC_e + CPDBR_e + \frac{PNRTS_e}{100} \cdot UPN_e \quad (40)$$

where:

All terms are defined above.

Finally, for the replacement policy of condemnation on failure, the equation is:

$$CPDO_e = CPDFL_e + UPN_e \quad (41)$$

where:

All terms are defined previously.

Benefit-to-Investment Ratio

Having calculated the total demands for the old and new items and the cost per average demand for each replacement policy, the cost to replace the old item and support the new items can be determined thusly:

$$CRO_e(T) = TDO_e(T) \cdot CPDO_e \tag{42}$$

where:

$CRO_e(T)$ is the cost to replace the old item.

$TDO_e(T)$ is the total demands for the old item.

$CPDO_e$ is the average cost per demand for the old item and the cost of the new item can be determined similarly:

$$CSN_e(T) = TDN_e(T) \cdot CPDN_e \tag{43}$$

where:

$CSN_e(T)$ is the cost to support the new item.

$TDN_e(T)$ is the total demands for the new item.

$CPDN_e$ is the average cost per demand for the new item.

The cost for time period T to support the old item if it had not been replaced by the new item is:

$$COSTO_e(T) = ADO_e \cdot CPDO_e T \tag{44}$$

where:

$COSTO_e(T)$ is the cost to support the old item if it had not been replaced with the new item.

ADO_e is the annual demands for the old item.

$CPDO_e(T)$ is the cost per average demand for the old item with natural attrition.

T is the time period.

The cost for time period T if the old item is replaced with the new improved reliability model is:

$$COSTN_e(T) = CRO_e(T) \cdot CSN_e(T) \tag{45}$$

where:

$COSTN_e(T)$ is the support cost if the old item is replaced with the new item.

$CRO_e(T)$ is the cost to replace the old item.

$CSN_e(T)$ is the cost to support the new item.

Note that $COSTN_e(T)$ will necessarily be different for each replacement policy.

<u>Availability Benefits</u>

The basic model and screening assumptions described earlier only consider benefits related to reduced support costs. If, however, an item has, when it failed, been causing aircraft to be grounded for maintenance, then improving the reliability would reduce the number of

failures, and this should proportionately reduce the average time the aircraft is grounded for maintenance on this item.

Failures, in turn are proportional to demands (in most cases equal demands). Thus by considering the total demands over the remaining life with the improved spare versus the unimproved spare, the degree to which the availability improves can be assessed. It is, in fact, the ratio of the number of fewer demands caused by improvement to the demands had there been no improvement.

Mathematically this is stated as:

$$AIF_e(T) = \frac{TDO_e(T) - TDN_e(T)}{TDO_e(T)} \tag{46}$$

where:

AIF_e is the availability improvement factor.

TDO_e is the total demands for the old item.

TDN_e is the total demands for the new item.

(T) indicates total life.

To determine the benefit due to increased availability, we simply multiply the availability improvement factor times the value of aircraft held down for maintenance due to this item prior to improvement.

$$OB_e(T) = AIF_e(T) \cdot VDAC_e \tag{47}$$

where:

OB_e is other benefits (see Eq (50)).

AIF_e is the availability improvement factor.

$VDAC_e$ is the value of down aircraft.

To calculate the value of aircraft down due to the item, the fraction of the time spent down due to this item is the ratio of down time to hours possessed. This times the number of aircraft in the inventory gives the number of aircraft down due to this item. The unit price of the aircraft is then assumed to be the value of one down aircraft.

$$VDAC_e = \frac{DT_e}{HP_s} \cdot INV_s \ UP_e \tag{48}$$

where:

$VDAC_e$ is the value of the downed aircraft.

DT_e is aircraft downtime in hours.

INV_s is inventory of aircraft.

UP_e is unit price of the item.

The gross savings then is the difference in cost between not implementing and implementing the improved reliability spare, thus:

$$GS(T) = COSTO(T) - COSTN(T) \tag{49}$$

where:

GS(T) is the gross savings; other terms defined above.

The (gross) benefit to investment ratio is then:

$$BTIR_e(T) = \frac{GS_e(T) + OB_e(T)}{INVEST_e} \qquad (50)$$

where:

GS_e is gross savings.

$BTIR_e(T)$ is the benefit to investment ratio.

$OB_e(T)$ is any other benefits.

$INVEST_e$ is the estimated investment.

This concludes the development of the development of the basic return on investment model.

Screening Assumptions

If the basic model, described in the previous sections of this chapter, is used to estimate returns on investments (benefit to investment ratios) on a small number of items, then individual engineering estimates on the reliability, unit price, and benefit of the new, improved item would be available and could be used directly in the model.

If, on the other hand, we wish to use the basic model in a computerized screening process, then no engineering estimate for improved items would be available, and some assumptions would have to be made regarding the new factors.

The first assumption required concerns the degree of reliability improvement. If the reliability improvement factor is defined as:

$$RIF_k = \frac{RN_e}{RO_e} \tag{51}$$

where:

RIF_k is the reliability improvement factor.

RN_e is the new improved reliability.

RO_e is the old reliability.

If the demand rate is assumed to be inversely proportional to reliability, then:

$$DRN_e = \frac{1}{RIF_k} \cdot DRO_e \tag{52}$$

where:

DRN_e is the demand rate for the new improved item.

RIF_k is the reliability improvement factor.

DRO_e is the demand rate for the old item.

Similarly, some assumptions need to be made regarding the unit price of the new item, the base and depot condemnation percentage, and the average cost per shop and depot repair. Recognizing that for the new items, no valid estimates of these values are available, the assumption incorporated into the model is that the values of the new equals the old.

Finally, some estimate must be made of the required investment. Generally, it is more expensive to redesign and test a high priced item to achieve improved reliability, than it is to achieve the same degree of improvement for a low cost item. Thus we might assume that investment is proportional to the unit price, thus:

$$INVEST_e = INVT_k \cdot UP_e \tag{53}$$

where:

$INVEST_e$ is the investment.

$INVT_k$ is the proportionality constant.

UP_e is the unit price.

Summary

This chapter has presented the development of the mathematical model. In Chapter IV the discussion will focus on the results of model application. Chapter V presents the conclusions and recommendations of the research effort.

CHAPTER IV

MODEL APPLICATION

Introduction

This chapter will present detailed analyses of the findings of this research effort. The research objectives of developing, applying, and evaluating a computerized screening methodology to locate aircraft equipment items for reliability improvement was met. This model was presented as Chapter III. The methodology for model application was discussed in Chapter II. A description of a current identification method is also found in Chapter II. This chapter will expand the discussions on the model application, provide a description of model outputs, and analyze the results. In addition, the analyses includes the identification of apparent deficiencies in the model and the data base.

Application

A complete computer run of all 31 aircraft was processed utilizing the master stock number to work unit code cross-reference portion of the LIST data base. This portion of the data base contained approximately 25,000 items. The total benefit-to-investment ratio (TBTIR)

threshold was set at five resulting in a listing containing those items, by aircraft, having a computed TBTIR of greater than five.[3] This threshold was set at five to obtain a representative sample of the cross-referenced items, to reduce the size of the output, and to eliminate those items with lower than a five to one potential TBTIR. This threshold is easily changed in the program so that varying sample sizes of output can be obtained as desired. A sample of the model output generated is presented in Figure 4.1.

The column headings are generally self-explanatory and equations for computing the resultant data were explained in Chapter III. The INDEX columns represents the support (SUP) benefit-to-investment ratio. The total (TOT) represents the computed total benefit-to-investment ratio (TBTIR). The column labeled REP POL represents the replacement policy. The number listed in this column corresponds to the replacement policy with the highest TBTIR. A number 1 in this column represents the normal attrition or replace-on-condemnation policy. A number 2 represents the policy of repair or replace at the base, and a number 3 represents the replace-on-failure case. These policies were explained previously in Chapter II.

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[3]Previous experimentation with this factor by the researchers was a prime determinant in the value of the TBTIR threshold parameter utilized.

AIRCRAFT	WORK UNIT CODE	MASTER STOCK NUMBER	MASTER STOCK NOUN	ITEM ALC	MGR CODE	ANNUAL DEMAND	COST PER DEMAND ($)	UNIT REPAIR COST ($)	UNIT PRICE ($)	TIME CONSTANT (YR)	GROSS SAVINGS EST REMAIN LIFE (K$) AVAIL	SUPPORT	TOTAL	INDEX SUP	TOT	REP POL
F04-E	13250	2620000884523	TIRE MLG	00	LTP	1902.	191.	73.	168.	.364	1055.	2093.	3148.	622.5	536.4	2
F04-E	13250	2620000884523	TIRE MLG	00	LTP	1902.	169.	73.	168.	.364	67.	1854.	1921.	551.4	571.4	3
F04-E	13260	2620000884523	TIRE MLG	00	LTP	1902.	184.	73.	168.	.364	530.	2034.	2564.	685.1	762.7	3
F04-E	1333A	1630009521432	WHEEL NOSE	00	C2H	245.	285.	0.	189.	2.828	61.	584.	645.	154.8	175.6	3
F04-E	13330	2620000884523	TIRE MLG	00	LTP	7606.	168.	73.	168.	.091	7.	7515.	7522.	2235.4	2237.6	3
F04-E	13330	2620000524222	TIRE NLG	00	LTJ	*****	1.	0.	81.	.019	339.	184.	523.	113.9	322.9	2
F04-E	13330	2620000524222	TIRE NLG	00	LTJ	*****	1.	0.	81.	.019	39.	158.	197.	97.7	121.8	2
F04-E	13330	2620000524222	TIRE NLG	00	LTJ	*****	0.	0.	81.	.000	91.	3.	94.	1.8	57.7	2
F04-E	1334L	1630001356311	DISC ROTG	00	C2H	*****	1.	0.	54.	.016	25.	88.	114.	82.2	105.5	2
F04-E	1334N	1630002262375	DISC STATR	00	C2H	*****	0.	0.	25.	.021	10.	22.	32.	43.4	63.1	2
F04-E	1342E	1650000790844	ACCUM HYD	0C	YRG	206.	162.	0.	155.	3.358	109.	83.	192.	26.8	62.1	2
F04-E	1343E	1630001376899	SENSOR WHL	00	C2H	1789.	71.	0.	85.	.387	103.	485.	589.	284.7	345.3	2
F04-E	1344.	1630001483225	PLATE	00	C2H	77.	117.	0.	67.	8.953	4.	253.	257.	188.8	192.2	3
F04-E	1344K	1630002262376	PLATE	00	C2H	3121.	12.	0.	128.	.222	0.	153.	153.	58.4	58.6	2
F04-E	1344L	1630001356311	DISC ROTG	00	C2H	*****	1.	0.	54.	.008	18.	177.	195.	164.2	181.3	2
F04-E	1344N	1630002262375	DISC STATR	00	C2H	*****	1.	0.	25.	.010	28.	200.	228.	401.3	457.6	2
F04-E	1344J	1630001483225	PLATE	00	C2H	77.	388.	0.	67.	8.953	106.	231.	337.	172.8	252.1	3
F04-E	1433N	1630002262375	DISC STATR	00	C2H	*****	0.	0.	25.	.021	35.	2.	36.	5.7	75.1	2
F04-E	2363x	5930001196607	SWITCH EGT	0C	TBS	3263.	249.	81.	397.	.462	6.	3057.	3063.	385.4	385.2	1
F04-E	23610	1680005189625	CAP ASSY	SA	HAA	2359.	11.	0.	65.	.242	88.	117.	205.	89.6	156.9	2
F04-E	27910	6620003693972	INDICATOR	0C	PNP	364.	127.	91.	106.	1.935	38.	114.	152.	53.9	71.7	3
F04-E	2392A	6685006845176	INDICATOR	SA	GBV	434.	444.	196.	401.	1.597	208.	222.	429.	27.7	51.6	3
F04-E	23920	6685006845176	INDICATOR	SA	GBV	434.	456.	196.	401.	1.597	470.	202.	673.	25.3	83.9	3
F04-E	2396J	2995001398730	THROTTLEBX	0C	MEJ	813.	570.	233.	575.	.879	35.	704.	739.	61.2	64.3	2
F04-E	41110	1650004359012	CONTROL	00	KAG	307.	519.	198.	1499.	2.256	1107.	455.	1561.	15.2	52.1	1
F04-E	4115A	1650001224922	FILTER	0C	YRK	1590.	21.	0.	18.	.436	8.	124.	131.	339.3	360.2	2
F04-E	42330	6140007581729	BATTERY	SM	I7Y	37.	3383.	0.	299.	18.555	115.	1014.	1129.	169.7	189.0	3
F04-E	42630	6115009031256	GENERATOR	00	KAG	421.	2168.	302.	1746.	1.646	2488.	-397.	2091.	-11.4	59.5	3
F04-E	4411L	5940001163963	CONTROL	00	KAM	1360.	386.	189.	436.	.586	76.	757.	833.	86.5	95.6	2
F04-E	4511E	1650000790844	ACCUM HYD	0C	YRG	206.	155.	0.	155.	3.358	93.	79.	172.	25.6	55.6	2
F04-E	4512C	1650000790844	ACCUM HYD	0C	YRG	206.	157.	0.	155.	3.358	138.	85.	224.	27.5	72.3	2
F04-E	45130	4320008184925	PUMP	0C	NEA	864.	795.	741.	1130.	1.831	279.	920.	1199.	40.7	53.1	2
F04-E	45130	1650000790844	ACCUM HYD	0C	YRG	206.	166.	0.	155.	3.358	119.	85.	204.	27.4	66.0	2
F04-E	511A0	6610000657276	INDICATOR	00	KBC	1270.	361.	362.	335.	.546	1385.	1856.	3241.	277.8	483.7	3
F04-E	51243	6605005118127	COMPASS	0C	MCJ	4428.	7.	0.	55.	.156	133.	113.	245.	103.1	224.2	2
F04-E	55100	6610004339240	RECORDER	0C	RFH	*****	543.	664.	27933.	.009	27.	170904.	170931.	305.9	306.0	1
F04-E	55110	6610009259974	MAGAZINE	0C	RFH	*****	258.	396.	2241.	.011	13.	64322.	64335.	1435.1	1435.4	1
F04-E	71439	5895002377952	CON INT SE	WR	CGE	*****	87.	218.	397.	.077	6.	8482.	8489.	1068.9	1063.7	2
F04-E	71600	5895007908764	AM2349A	WR	CGH	*****	318.	519.	3971.	.084	116.	15693.	15809.	197.6	199.3	2
F04-E	730PF	1270000165006	CIR CD AY	WR	FLC	56.	336.	4013.	394.	14.619	0.	1232.	1232.	156.3	156.3	2

Figure 4.1. Example Output--All Stock Classes

An analysis of the initial screening revealed numerous examples of high potential benefit-to-investment ratios. As the researchers expected, a number of high potential benefit avionics, engine, and airframe components were represented. Also it was observed that a great number of 1650 stock class items such as valves and actuators were identified in the output as high potential return-on investment candidates. Therefore, the 1650 stock class was chosen for further investigation. This narrowed the scope and limited the investigation to one AFLC depot, Oklahoma City Air Logistics Center (OCALC), and to one stock class (1650).

The next step was to execute the computer program on only the 1650 stock class, again at a TBTIR threshold of five. An example of this output is presented in Figure 4.2.

The 1650 computer product contained approximately 333 WUC/NSN combinations ranging from 5.3 to 2170.7 TBTIR. Because one stock number often has several applications within one aircraft and applications on more than one aircraft, the list was reexamined. This revealed that the list contained 220 individual 1650 class National Stock Numbers (NSN). This listing was further studied and select items with a large TBTIR were identified for additional study and analyses. These items are presented in Table 4.1. To evaluate the accuracy, potential usefulness, and areas for model/data improvement, selected candidates in the

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AIRCRAFT	WORK UNIT CODE	MASTER STOCK NUMBER	MASTER STOCK NOUN	ITEM ALC	MGR CODE	ANNUAL DEMAND	COST PER DEMAND ($)	UNIT REPAIR COST ($)	UNIT PRICE ($)	TIME CONSTANT (YR)	GROSS SAVINGS EST REMAIN LIFE (K$) AVAIL	SUPPORT	TOTAL	INDEX SUP	TOT	REF POL
F00-E	1233K	[illegible]	CYLINDER	OO	KAG	153.	798.	189.	591.	4.516	341.	-118.	223.	-3.5	19.3	3
F00-E	1342E	[illegible]	ACCUM HYD	OO	YRG	266.	162.	0.	155.	3.358	109.	83.	192.	26.8	62.1	2
F00-E	1342F	[illegible]	ACCUM HYD	OO	YRG	413.	7.	0.	155.	1.679	12.	4.	15.	1.4	5.3	2
F00-E	1432F	[illegible]	CYL STAP	OO	KAN	309.	1444.	1091.	6691.	2.246	1084.	1296.	2381.	9.4	17.3	1
F00-E	1433E	[illegible]	CYL TE FLA	OO	KAH	270.	1875.	513.	1445.	2.569	686.	-22.	664.	-.8	23.8	3
F00-E	2371J	[illegible]	DRIVE TRAN	OO	NVM	1176.	1242.	2196.	11330.	.589	516.	5411.	5331.	23.9	26.2	1
F00-E	2373J	[illegible]	VALVE	OO	YOE	542.	4.	0.	63.	1.079	0.	10.	10.	7.8	7.8	2
F00-E	2373J	[illegible]	DRIVE TRAN	OO	NVM	1176.	1218.	2196.	11330.	.589	0.	5263.	5263.	23.2	23.2	1
F00-E	2373E	[illegible]	DRIVE TRAN	OO	NVM	1176.	1218.	2196.	11330.	.589	0.	5262.	5262.	23.2	23.2	1
F00-E	2373K	[illegible]	DRIVE TRAN	OO	NVM	1176.	1218.	2196.	11330.	.589	0.	5262.	5262.	23.2	23.2	1
F00-E	2373J	[illegible]	DRIVE TRAN	OO	NVM	1176.	1218.	2196.	11330.	.589	0.	5262.	5262.	23.2	23.2	1
F00-E	2373J	[illegible]	DRIVE TRAN	OO	NVM	1176.	1346.	2196.	11330.	.589	173.	5864.	6037.	25.9	26.6	1
F00-E	2374A	[illegible]	DRIVE TRAN	OO	NVM	1176.	1218.	2196.	11330.	.589	0.	5265.	5265.	23.2	23.2	1
F00-E	2374J	1650019124367	ELEMENT	OO	YOE	3324.	2.	0.	48.	.209	0.	26.	26.	33.4	33.4	2
F00-E	4113A	1650011224922	FILTER	OO	YRK	1590.	21.	0.	18.	.436	6.	124.	131.	339.3	363.2	2
F00-E	4311E	[illegible]	ACCUM HYD	OO	YRG	266.	155.	0.	155.	3.358	93.	79.	172.	25.6	55.6	2
F00-E	4311J	[illegible]	ACCUMULATOR	OO	YRG	4.	3510.	0.	80.	164.024	16.	1.	17.	.9	18.8	2
F00-E	4312C	[illegible]	ACCUM HYD	OO	YRG	266.	157.	0.	155.	3.358	136.	85.	221.	27.8	72.3	2
F00-E	4312J	[illegible]	ACCUM HYD	OO	YRG	266.	57.	0.	155.	3.358	9.	28.	37.	9.1	11.9	2
F00-E	4313J	[illegible]	ACCUM HYD	OO	YRG	266.	156.	0.	155.	3.358	119.	85.	204.	27.4	66.0	2
F00-E	4313J	[illegible]	ACCUMULATOR	OO	YRG	4.	13173.	0.	80.	164.024	55.	13.	68.	8.4	42.6	3
F00-E	4321J	[illegible]	DRIVE TRAN	OO	NVM	588.	1256.	2196.	11330.	1.179	223.	2536.	2762.	11.2	12.2	1

Figure 4.2. Example Output--1650 Stock Class

Table 4.1

Items Identified For Detailed Analysis

NSN	NOUN	AIRCRAFT	WUC	TBTIR	REP POL
1650005115267	Valve	KC135A	46814	12.3	1
1650006272617	Cylinder	B52G	14AJC*	91.2	3
		B52H	14AJC*	123.5	3
1650005708397	Valve Ay	KC135A	13CBJ*	201.9	3
		KC135A	13CBK	29.6	2
1650007302850	Valve	T38A	52118	90.2	3
1650008593985	Cylinder	T38A	14000	147.4	1
1650000053695	Drive Tran	F4C	2373C	8.1	1
			2373E	8.1	1
			2373K	8.1	1
			23730*	10.2	1
		F4D	23700	14.2	1
			2373C	13.7	1
			2373D	13.7	1
			2373E	13.7	1
			2373K	13.7	1
			2373M	13.7	1
			23730*	16.5	1
		F4E	2373D	23.2	1
			2373E	23.2	1
			2373K	23.2	1
			2373U	23.2	1
			23730*	26.6	1
			2374A	23.2	1
			46210	12.2	1
1650004266840	Drive CSD	C5A	42EAA	21.4	1
			42EAB*	8.6	1

Table 4.1 (continued)

NSN	NOUN	AIRCRAFT	WUC	TBTIR	REP POL
1650001033553	Gear Box	B52G	23CAD	23.0	2
			42BBB	8.3	2
			42BBE	8.2	2
			42BBF*	9.9	2
			42BB5	8.3	2
			42BCH	8.6	2
1650001033554	Transmission	B52G	42BBA	6.2	2
1650006408486	Accumulator	KC135A	13CBM*	104.7	3
			14BJC*	302.1	3
			46825*	256.2	3
		B52D	45AEN*	27.1	3
		C130A	1342D*	9.8	3
			13420	18.1	2
		C130B	1342D*	11.2	3
1650006403491	Accumulator	C5A	45LER	62.4	3
		C130A	454AA*	30.6	3
			454AB*	10.0	3
		C130B	454AA*	33.1	3
			454AB*	8.8	3
			454AC	7.5	3
		C130E	1342D*	80.6	3
			13420	295.1	2
			454AA*	75.0	3
			454AB*	53.7	3
			454AC*	14.5	3
			455AA	41.1	3
		T37	45130*	726.2	2
			45131*	6.0	2

Table 4.1 (continued)

NSN	NOUN	AIRCRAFT	WUC	TBTIR	REP POL
1650009303160	Drive Assy	C141A	23SQA*	102.1	2
			23SQD	54.2	2
			23SQP*	59.8	2
			42HAL	315.7	2
1650010224922	Filter	C130A	41315*	5.4	2
			41325	5.3	2
			41415*	12.7	2
		C130B	41315*	11.7	2
			41325	8.6	2
			41333	24.7	2
			41415*	52.3	2
			41533	10.0	2
		C130E	41315*	40.0	2
			41324	9.5	2
			41325	88.4	2
			41333	18.4	2
			41415*	168.5	2
			41425	63.2	2
			41531	37.7	2
		F4C	4115A*	102.1	2
		F4D	4115A*	267.4	2
		F4E	4115A*	360.2	2
1650006898259	Accumulator	B52G	14FGG	141.9	3
1650006083200	Drive Alt	B52D	42ABA	11.4	2
1650004485560	Cylinder	KC135A	14APD	87.1	3
1650008727516	Turbine	C130A	24210*	189.5	1
			24215	7.3	1

Table 4.1 (continued)

NSN	NOUN	AIRCRAFT	WUC	TBTIR	REP POL
		C130B	24210	258.1	1
			24215	10.1	1
		C130E	24200*	10.9	1
			24215*	10.3	1
			24210	1117.1	1
		C130E	24211	10.1	1
			24212	10.2	1
			24213	10.1	1
			24215*	44.1	1
1650008720320	Valve	C141A	11BBL	126.8	2
			14FBH	17.9	2
			14FCB	258.9	2
			14FCD*	15.5	3
1650001136912	Bellows	T38A	45115	790.6	2
1650001690950	Cylinder	C141A	13AAB	20.9	3
			13ABB*	132.5	3
1650009012807	Element	C141A	14FCF	9.2	2
1650008369769	Wire Harness	C141A	23STB	139.1	3
			23S99*	2170.7	3
			23TSB	90.6	3
1650008564613	Transmission	KC135A	42177	13.1	2
			42194*	17.8	2
1650009914223	Exten Unit	A7D	14BCL	59.3	2

*WUC with a relatively high number of primary NSN occurrences.

1650 stock class were discussed with Equipment Specialists (ES) at the Oklahoma City Air Logistics Center (ALC).

Results of Selected Items Investigation

The analyses presented in this section are the results of interviews with selected equipment specialists at the OCALC. Five of the WUC/NSN combinations from Table 4.1 are discussed as illustrations. These items are presented because they represent a wide range of concerns. For example, some of the items showed high TBTIR, but they were not seen as problems by the equipment specialists. Others on the list were acknowledged by equipment specialists as being problem items. The five items selected for discussion are: 1650005708397, Valve Assembly; 1650005115267, Boom Telescoping Valve; 1650006408486, Accumulator; 1650010224922, Filter; and 1650000053695, Drive Transmission.

1650005708397--Valve assembly. Based on the assumptions in the model, the estimated ROI is 201.9. The equipment specialist indicated that this item is not considered a problem item. The depot condemnation rate is two percent and the service life is 6000 hours. However, the unit price is given as $99.88 and the unit repair cost is $101.77; therefore, the Air Force is spending more to repair the item than it orginally cost.

The D056 data indicates that, during the period of the data, a total of 4847.7 maintenance manhours were expended on this item. Also 3284 maintenance actions were recorded against it. The IROS-LSC was $22,227 for the period of data.

The combination of these factors led the researchers to the conclusion that this item should be a candidate for reliability improvement engineering investigation even though the equipment specialist does not see it as a problem from his perspective.

<u>1650005115267--Boom telescoping valve</u>. The estimated ROI for this item, as computed by the model, is 12.3. This value, when compared to some of the other ROI's in the KC-135A section of the output, is relatively small. The depot condemnation rate was 53 percent for the period of the data. The equipment specialist indicated that this item has been a subject of concern for some time. He stated that the problem was case failure. Over the last five years three engineering studies have been conducted to determine the cause of the failures. These studies have failed to recommend adequate corrective measures.

This item was not repairable at the base 73 percent of the time. The depot condemnation rate was 53 percent. There were 151 failures reported and these failures caused 2947 maintenance manhours to be expended. The KC-135A

aircraft was not capable of mission performance for 4730 hours of the data period. These data appear to support the concerns of the equipment specialist.

<u>1650006408486--Accumulator</u>. As illustrated in Table 4.1, this item has seven applications on four weapon systems that are in the data base. In addition, this item has applications on 23 other systems that are not included in the data base.

The model computed ROI ranges from 9.8 to 302.1. On the KC-135A, WUC 13CBM, the total number of maintenance actions for the period was 908, the maintenance manhours was 3117, and the IROS-LSC was 14,853. On the same aircraft WUC 14BJC accounted for 5404.2 maintenance manhours, 1031 maintenance actions and 26,461 in LSC. The depot condemnation rate is 15 percent for this item. The average number of items installed on the 27 aircraft for the 1977 calendar year was 1936. With this many accumulators installed, it is evident that any improvement in the reliability of the item would be a welcome and beneficial undertaking.

<u>1650010224922--Filter</u>. This filter appeared in the output product on the following aircraft under various Work Unit Codes: C130A, C130B, C130E, F4C, F4D, F4E. This indicates that the filter is a common item with many applications. Since it is an EOQ item, no D041 data was available at OCALC. An equipment specialist did, however, show the

researchers a Military-Standard drawing of the item and explained that the filter is a common air filter. In this case a reliability improvement investigation as such may not be appropriate. This $18.00 item is performing its task satisfactorily. Unless a technological breakthrough reveals new, more reliable methods of filtration, we will have to live with the maintenance of frequent inspection and periodic replacement of such items.

<u>1650000053695--Drive transmission</u>. This item is a constant speed drive (CSD) which is an expensive equipment item which converts varying engine speeds to a constant output speed. This constant output speed is required to drive the generator which produces 400 Hz electrical power to operate aircraft electrical systems (15:7). CSD managed by OCALC are applicable to 19 configurations, 21 aircraft applications (10 fighters, five cargo, and six bombers) and have a total inventory value of $236,000,000. They consume approximately 200,000 overhaul manhours annually. For these reasons, CSDs are the subject of a special project: Constant Speed Drive, Deep Look Program [CSD/DLP] (15:9).

This particular CSD is of interest because it is the subject of an Unsolicited Value Engineering Change Proposal (ECP) number 34309B-R2 submitted by Sunstrand Corporation of Rockford, Illinois. The ECP recommends an engineering change to the P. D. Spline Shaft to provide a "wet pad"

lubrication system to increase the efficiency and effectiveness of the lubrication of the spline. The results of incorporating this change will reduce the incidence of spline wear, reducing the number of spline replacements required, thereby improving the reliability of the CSD. The Sunstrand Corporation estimates that the average annual savings to the USAF would be $1,838,953, and the implementation costs would be $400,240, a TBTIR of 4.59/1 for a one year period (12:10-11). The extension of these savings over the remaining life of the F4 aircraft models to which it is applicable yields a remaining life savings of $31,262,201 (17 year effective remaining life (ERL)) calculated as shown in Chapter III.

The model computes TBTIRs for those WUC/NSN combinations with the most number of Master Stock Number occurrences from 10.2 to 26.6. This is the estimated TBTIR over the remaining life calculated in the model under the assumptions explained in Chapter III. The contractor's ERL TBTIR indicated an estimated ratio of 78.1 to 1. Since the computations are figured utilizing the factors on a particular WUC/NSN cross-reference, the TBTIRs can be summed to obtain a total TBTIR for the NSN on that particular series of aircraft (in this case the F4 series). When you total the high primary Master Stock occurrence WUC's TBTIRs, the result is a total TBTIR of 53.3 (10.2 + 16.5 + 26.6). Since Sunstrand's estimated savings and investments are based on

engineering estimates of parts, labor, and documentation charge costs, his estimates are probably more realistic than the model's estimate. Since the primary emphasis of this research effort is to develop and evaluate a generalized model for the identification of candidates for further investigation, the model's results compare favorably to those of the Sunstrand Corporation. Furthermore, an ECP requires many manhours in preparation and can cost thousands of dollars to prepare. On the other hand, the process by which the model identified this CSD can be accomplished with a relatively small amount of computer time and manhour expenditures.

False candidate identification. Some items in the data base receive a high number of maintenance actions due to various inspection and/or mandatory time change requirements. These mandatory time change items are often safety related items and for that reason alone are inspected and replaced at shorter time intervals than other non-time change items.

For example, on the T38A NSN 1650001136912, WUC 4511B, Bellows, is a safety related time change item. It is mandatory to change it at 1200 hours operation. The unit price is $20.00 and it is not considered a problem item by the ALC equipment specialist. The algorithm computed the TBTIR to be 70.8. Since the large number of actions are

not directly related to reliability, but to scheduled replacement, improving the reliability would not be beneficial, and thus this is a false candidate.

LIST Data Base Problems

Unit price (UP). During the visit to Oklahoma City Air Logistics Center, the results generated by running the model were discussed with item management personnel. One individual expressed concern over the unit price reflected in the data base. He pointed out that the unit price is only updated in the USAF supply cataloguing system upon new procurement of the particular NSN. In the supply system if an item was last procured 10 years ago, the purchase price at that time is the unit price of the item until the item is again purchased. The results of this revelation is that the unit prices reflected in the data base are not always representative of the price that would have to be paid if the same item were procured today.

The unit price is used in the computer program, directly and indirectly in 13 equations and several program control points. It must be realized that the application of the model without accurate and current unit prices can affect the decision to choose one replacement policy over another. This can result in an expectation of a particular return-on-investment (ROI) when in fact another somewhat different ROI is being realized.

The unit price is used in the investment model to calculate the Total Benefit-to-Investment ratio. If, for instance, the UP on the supply record is $6000.00, and that UP is 10 years old, the reprocurement price for the same item may be $18,000.00 today. Using 20 times UP as the investment assumption, under the old price the investment would be $120,000, and under the current price it would be $360,000. If the more current UP were used in the model, the total effect on TBTIR is that the expectation is reduced. If we underestimate the investment because of a lower UP required to double the MTBF, the actual TBTIR will be lower than the model presents.

While the number of unit price errors of this magnitude are small, the importance of carefully investigating candidates identified by the screening process is emphasized.

Quantity per application (QPA). The source of the quantity per application (QPA) is the K051 (IROS). The QPA in the K051 is related to the Work Unit Code (WUC). When the WUCs/NSNs are cross-referenced, often the total number of NSN's in the data base exceeds the actual quantity of the NSN actually found on the aircraft. For example, Table 4.2 shows the WUC, QPA and the number of primary stock number occurrences. These combinations appear in the data base for NSN 1650006408486 on the KC135A aircraft. The D041 reflects a QPA of four for this item on the KC135A. At first glance

Table 4.2
NSN 1650006408486--KC135A
QPA Example

ITEM	WUC	QPA	NSN OCCURRENCES
1	13CBM	1	104
2	13CBN	2	5
3	14BJC	2	268
4	14BJG	1	2
5	14CAO	1	2
6	46825	1	191
7	46826	1	1
8	46994	1	5

it appears that the data base indicates a total QPA of 10. However, if you add the QPAs from items 1, 3, and 6, the total is four which matches the D041. Those items have a high number of NSN occurrences compared to the other entries. Improper maintenance data recording may have caused the extraneous WUC/QPA/NSN cross-reference. Further examination of the table reveals that WUC errors could have been committed due to the similarities of the WUCs. Items 1 and 2 are 13CBM and 13CBN respectively with 13CBM suspected as the correct code because of the high number of NSN occurrences. Hasty recoding of the data or misinterpretation of the code by data entry personnel could be the cause of the error. Similar analysis applies to items 3 and 4 and items 6 and 7.

On the F4E, the D041 reflects NSN 1650000053695 with a QPA of two. In the data base WUC 23730 has 628 primary NSN occurrences and reflects a QPA of two. However, there are six other WUC entries in the 2373x area each with an extremely low number of occurrences.

On the C130A, NSN 1650006408486, the QPA for WUC 13420 is actually four while the data base reflects a QPA of 40. Glaring errors such as this must be taken into consideration when utilizing any data base. In this instance, the errors could be in the K051 or it could have been caused in the data transfer process (from the K051 to LIST).

Summary

This chapter presented model application, results of the application, and model/data base deficiencies. It can be seen from the preceding examples of the model output that in some cases the items identified will be good candidates for further reliability improvement investigation. It must be kept in mind that this "further investigation" means (1) a thorough analysis of the data that promulgated the TBTIR; (2) investigation of the feasibility of reliability improvement of the particular item; (3) the investigation to ascertain if there are ongoing studies or ECPs on the item; (4) and many other factors.

The identification of items through the model is only the starting point from which to begin the thorough investigation of the reliability improvement possibilities for the item. The advantage to processing the model against the data base is that this computerized identification process is more efficient than current identification techniques, in terms of manpower requirements and the data retrieval process. Once the initial identification is accomplished by the model, the engineering proposals and estimated costs and resultant life cycle savings must still be computed.

As a result of the analyses, it appears that if an item currently has a low or consistent depot condemnation rate, it generally is not considered to be a problem item. This discounts the possible high number of maintenance actions taking place in the field, therefore ignoring a vast number of potential reliability improvement candidates.

Applying the model to the LIST data base revealed that the model can be used if the user recognizes the deficiencies previously discussed. Chapter V presents the summary, conclusions, and recommendations.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The principle objectives of this study were to develop, apply, and evaluate a computerized screening methodology which could identify aircraft equipment items for reliability improvement. These same items, if improved, would have a potential high return-on-investment if introduced as a spare on a normal attrition or replacement-on-failure basis. The model described in Chapter III, and the computer program depicted in Appendix B is presented in response to the principle objective of model development.

The model is developed for general use and is applicable only to the LIST data base which currently contains data elements pertaining to 31 operational Air Force aircraft. The model was translated into a computer program and has been applied to the LIST data base. The model can be exercised, using the computer program to screen the data for identification of potential reliability improvement candidates.

Conclusions

The research objectives were met. A computerized modeling methodology was developed for identifying

reliability improvement candidates. However, the model and the data base can be expanded and improved. The model has been applied to the 1650 FSC of items and modeling output has been evaluated with the assistance of equipment specialists assigned to the Oklahoma City Air Logistics Center.

The advantages of the ROI model over the current approaches described in Chapter II are many. Firstly, the ROI model incorporates a data base which contains data retrieved from the various sources indicated in Figure 2.3 of Chapter II. This compilation of data into one data source is a more powerful and efficient approach for data analysis. Secondly, the computer is capable of analyzing vast amounts of data (i.e., 93,000) in a short amount of time (300 seconds approximately). Thirdly, when utilizing numerous manual sources of data (i.e., telephone calls from several sources) the possibility of inadvertantly discarding important information is high. Fourthly, the ROI model and data base have the potential of greatly reducing the time span required to identify potential reliability improvement candidates. For instance, it may take several months for a trend to develop utilizing MDRs and other manual reports from field and other echelons. Also the establishment of trends from overhaul facilities could span several months.

Figure 5.1 represents the block diagram of the proposed method of the identification of aircraft equipment

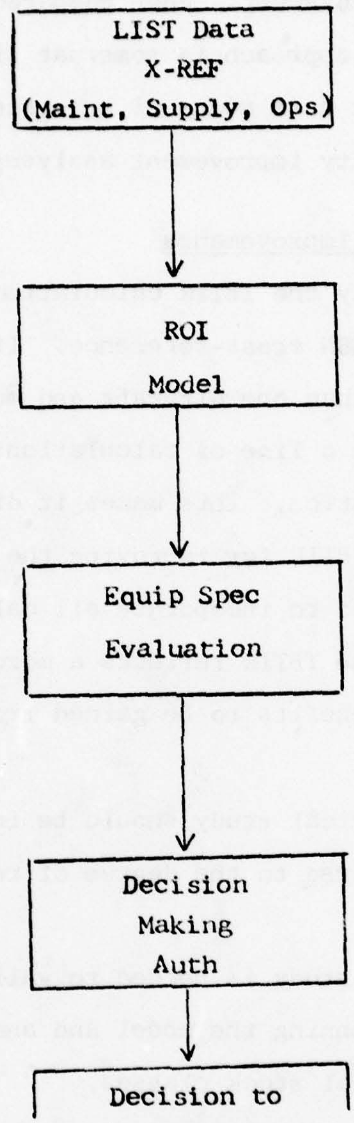

Figure 5.1. Proposed Approach

for reliability improvement. When compared to Figure 2.1 of Chapter II, this approach is somewhat simplified and hence more efficient as a means of accessing data and conducting reliability improvement analyses.

Recommendations for Improvements

1. Currently the TBTIR calculations are performed by aircraft by WUC/NSN cross-reference. If the NSN is applicable to more than one aircraft and more than one WUC within that aircraft a line of calculations is presented for each WUC/MDS combination. This makes it difficult to determine the true TBTIR for improving the NSN. Recommend the model be modified to incoporate all calculations at the NSN level so that the TBTIR reflects a more realistic estimation of the benefits to be gained from the reliability improvement.

2. An empirical study should be initiated to relate the investment required to the degree of reliability improvement.

3. Further study is needed to validate the model. This could entail running the model and analyses over a wider range of Federal stock classes.

4. The data base should be upgraded to include all United States Air Force Aircraft weapon systems.

5. The data base WUC/NSN cross-reference should be expanded and made comprehensive.

6. The data base should be periodically updated to include current data.

7. Additional study could be directed towards model modification to include other types of failure distributions. Presently, the model developed assumes the exponential distribution.

APPENDIX A

DEFINITIONS

Availability--A measure of the degree to which an item is in the operable and committable state at the start of the mission, when the mission is called for at an unknown (random point in time).

EOQ--Economic Order Quantity Item--An item normally consumed in use, i.e., not repaired upon failure, generally a low cost item termed "throw away" or failure.

Failure--The inability of an item to perform within previously specified limits.

Failure, Random--Any failure whose occurrence is unpredictable in an absolute sense but which is predictable only in a probabilistic or statistical sense.

Failure Rate--The number of failures of an item per unit measure of life (cycles, time, miles, events, etc., as applicable for the item).

Maintainability--A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

Maintenance--All actions necessary for retaining an item in or restoring it to a specified condition.

Mean-Time-Between-Failures (MTBF)--For a particular interval, the total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval. The definition holds for time, cycles, miles, events, or other measure of life units.

Mission--The objective or task, together with the purpose, which clearly indicates the action to be taken.

NRTS--Not Repaired This Station--When an item fails and the repair is beyond the capability of the unit to repair because of lack of skills, equipment, replacement parts, etc., the item is NRTS and processed to a higher level repair facility with the appropriate capability. A series of maintenance-action-taken codes is assigned to indicate the cause of the NRTS action (e.g., action taken code 2 means "Bench-checked--NRTS--Lack of Equipment, Tools or Facilities [17:V-002]").

Operable--The state of being able to perform the intended function.

Operational--Of, or pertaining to, the state of actual usage.

O&S Costs--Operations and Support Costs--All costs associated with operating the weapon system from delivery to retirement.

Ready Rate, Operational (Combat)--Percent of assigned items capable of performing the mission or function for which they were designed, at a random point in time.

Reliability--The probability that an item will perform its intended function for a specified interval under stated conditions.

Repair Cycle Item--When a malfunction is detected and the cause isolated, the item causing the discrepancy is normally repaired and returned to service through the supply system.

System Effectiveness--A measure of the degree to which an item can be expected to achieve a set of specific mission requirements, and which may be expressed as a function of availability, dependability and capability.

Time, Down (Downtime)--That element of Time during which the item is not in condition to perform its intended function.

Time, Up (Uptime)--That element of Active Time during which an item is either alert, reacting, or performing a mission [18:2-10].

WUC--Work Unit Code--A code consisting of five alpha-numeric characters to identify the system, subsystem or component for which a maintenance action was recorded [17:II-001].

APPENDIX B

VARIABLE LIST/COMPUTER PROGRAM

AD-A059 566 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 1/5
A COMPUTERIZED METHODOLOGY FOR THE IDENTIFICATION OF AIRCRAFT E--ETC(U)
JUN 78 R BAKER, D J HOLLINGSWORTH

UNCLASSIFIED AFIT-LSSR-31-78A NL

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SAC	=	Aircraft Mission Design Series (MDS) from System Data
ERL	=	Effective Remaining Life
ACUP	=	Aircraft Unit Price
HP	=	Hours Possessed
INV	=	MDS Inventory
AFFH	=	Annual Fleet Flying Hours
KAC	=	Aircraft MDS from Equipment Data
KWUC	=	Work Unit Code
QPA	=	Quantity per Application
UMMH	=	Unscheduled Maintenance Manhours
SMH	=	Shop Manhours
NORMG	=	Not Mission Capable for Maintenance
NORMF	=	Partial Mission Capable for Maintenance
MSN	=	Master Stock Number
MNOUN	=	Master Stock Number Noun
UP	=	Unit Price of Equipment Item
DRO	=	Demand Rate of Old Item
IM	=	Item Manager (ALC)
IMC	=	Item Manager Code
PNRTS	=	Percent Not Repairable This Station
PBC	=	Percent Base Condemnation
PDC	=	Percent Depot Condemnation
URC	=	Unit Repair Cost

ARS	=	Average Requisition Size
ADO	=	Annual Demands of Old Item
RF(I)	=	Replacement Factor for Case I
TC(I)	=	Time Constant
TDOL(I)	=	Total Demands of Old Item for Remaining Life (Assuming something is done)
RIF	=	Reliability Improvement Factor
DRN	=	Demand Rate of New Item
TDNL(I)	=	Total Demands of New Item for Remaining Life
CPDFL	=	Cost per Demand for Flight Line Action
CPDBC	=	Cost per Demand for Base Condemnation
CPDBR	=	Cost per Demand for Base Repair
CPDDC	=	Cost per Demand for Depot Condemnation
CPDDR	=	Cost per Demand for Depot Repair
CPDN	=	Cost per Demand of New Item
CPDO(I)	=	Total Cost per Demand of Old Item for Case I
CROL(I)	=	Cost of Replaced Old Items Remaining Life
CSNL(I)	=	Cost of Replacement New Items Remaining Life
COSTNL(I)	=	Cost of Old and New Items Remaining Life
COSTOL	=	Cost of Old Items Remaining Life, no Reliability Improvement
TDIL	=	Total Demands Remaining Life with Improvement Program
TDUL	=	Total Demands of Item Remaining Life, no Improvement
DEMFAC(I)	=	Demand Factor, i.e., Ratio of Demand Improved to Unimproved, Case I

VDAM	=	Value of Down Aircraft for Maintenance
AB(I)	=	Availability Benefits
SCB(I)	=	Support Cost Benefits
GSL(I)	=	Gross Savings for Remaining Life
IC	=	Investment Coefficient
INVEST	=	Amount of Investment
CBTIB(I)	=	Support Cost Benefit-to-Investment Ratio
TBTIR(I)	=	Total Benefit (Support Cost and Availability) to Investment Ratio

```
      PROGRAM PREFER(INPUT,OUTPUT,TAPE1=/117,TAPE2,TAPE3,TAPE4,TAPE5)
      INTEGER SAC(31),ERL(31),INV(31),AFFH(31),SAVEAC,QPA,HP(31)
      REAL INVEST,NERL(3)
      DIMENSION RF(3),TC(3),TDOL(3),TDNL(3)
      DIMENSION CBTIR(3),TBTIR(3),TTC(3),GSL(3)
      DIMENSION CPOD(3),CPOL(3),CSNL(3),COSTNL(3)
      DIMENSION TDIL(3),DEMFAC(3),AB(3),SCB(3),ACUP(31)
      REWIND 1
      REWIND 2
      NPRINT = 200
C
C          READ SYSTEM DATA
C
      DO 10 I = 1,31
      READ 901,SAC(I),ERL(I),ACUP(I),HP(I),INV(I),AFFH(I)
   10 CONTINUE
C
C          READ EQUIPMENT DATA
C
      SAVEAC = 5HXXXXXX
  100 READ(1,802) KAC,KHUC,QPA,UMMH,SMN,NORMG,NORMF,MSN,MNOUN,UP,DRO,
     1     IM,INC,PNRTS,PBC,PDC,UPC,ARS
      IF(EOF(1)) 500,110
  110 CONTINUE
      IF(MSN.LT.1650000000000)  GO TO 100
      IF(MSN.GT.1650999999999)  GO TO 100
  115 IF(KAC.EQ.SAVEAC) GO TO 150
      DO 120  I = 1,31
      IF(SAC(I).EQ.KAC)  GO TO 125
  120 CONTINUE
  125 CONTINUE
      KK = I
      AFHPA = (1000.0*AFFH(KK))/INV(KK)
      C1 = 10.0*AFFH(KK)
      SAVEAC = KAC
      NPRINT = 200
  150 CONTINUE
C
C          CALCULATE ANALYTICAL VALUES
C
C          CASE1 = REPLACE ON CONDEMNATION (ROC)
C          CASE2 = REPLACE OR REPAIR AT BASE (RORAB)
C          CASE3 = REPLACE ON FAILURE (ROF)
C
      IF(UP.LE.0) GO TO 100
      IF(DRO.LE.0) GO TO 100
      IF(ARS.GT.0) GO TO 100
      ADD = C1*DRO*QPA
      RF(1) = PBC+(PNRTS*PDC)
      RF(2) = PBC+PNRTS
      RF(3) = 1.00
      DO 175  I = 1,3
      IF(RF(I).EQ.0) RF(I) = 1.00
      TC(I) = 100.0/(RF(I)*AFHPA*QPA*DRO)
      TTC(I) = ERL(KK)/TC(I)
      IF(TTC(I).LE.675)  GO TO 170
      TTC(I) = 675.0
```

```
      NERL(I) = 675.0*TC(I)
      WRITE(3,601) KAC,KHUC,NERL(I)
  601 FORMAT(10X,A6,5X,A5,5X,F5.2)
  170 TOOL(I) = C1*DRO*QPA*TC(I)*(1.0-EXP(-TTC(I)))
      RIF = 2.0
      DRN = DRO/RIF
      TONL(I) = C1*DRN*QPA*(ERL(KK)+(TC(I)*(EXP(-TTC(I))-1.0)))
  175 CONTINUE
      CPOFL = (UMMH*14.0)/ADD
      CPOBC = PBC*UP
      CPOBR = (SMH*14.0)/ADD
      CPODC = PNRTS*PDC*UP
      CPODR = PNRTS*(1.00-PDC)*URC
C
      CPON = CPOFL + CPOBC + CPOBR + CPODC + CPODR
C
C          COST PER DEMAND FOR THE THREE CASES
C
      CPOD(1) = CPON
      CPOD(2) = CPOFL + CPOBC + CPOBR + (PNRTS*UP)
      CPOD(3) = CPOFL + UP
C
      DO 195  I = 1,3
      CROL(I) = CPOD(I)*TOOL(I)
      CSNL(I) = CPON*TONL(I)
      COSTNL(I) = CROL(I) + CSNL(I)
      COSTOL = CPOD(1)*ADD*ERL(KK)
      TOIL(I) = TOOL(I) + TONL(I)
      TOUL = ADD*ERL(KK)
      DEMFAC(I) = TOIL(I)/TOUL
      VDAM = (NORMF + NORMG)*INV(KK)*ACUP(KK)/(HP(KK)*1000.0)
      AR(I) = (1.0 - DEMFAC(I))*VDAM*1000.0
      SCR(I) =(COSTOL - COSTNL(I))/1000.0
      GSL(I) = SCR(I) + AR(I)
      IC = 20.0
      INVEST = IC*UP/1000.0
      CBTIR(I) = SCR(I)/INVEST
      TBTIR(I) = GSL(I)/INVEST
  195 CONTINUE
C
C          CHECK WHICH CASE HAS THE GREATEST BTIR
C
      IF(TBTIR(1).GT.TBTIR(2))  GO TO 210
      IF(TBTIR(2).GT.TBTIR(3))  GO TO 230
      GO TO 240
  210 IF(TBTIR(1).GT.TBTIR(3))  GO TO 220
      GO TO 240
  220 I = 1
      GO TO 250
  230 I = 2
      GO TO 250
  240 I = 3
  250 CONTINUE
      IF(TBTIR(I).LT.5.0)  GO TO 100
C
C          CONVERT DECIMALS BACK INTO PERCENTS
C
      PBC = 100.0*PBC
```

```
      PDC = 100.0*PDC
      PNRTS = 100.0*PNRTS
      NPRINT = NPRINT + 1
      IF(NPRINT.LT.40) GO TO 350
  300 WRITE(2,800)
      WRITE(2,803)
      WRITE(2,900)
      WRITE(2,901)
      WRITE(2,902)
      WRITE(2,903)
      NPRINT = 0
  350 CONTINUE
      WRITE(2,806) KAC,KNUC,NSN,MNOUN,IM,IMC,ADD,CPDD(I),UFC,UP,IC(I),
     1     AB(I),SCR(I),GSL(I),COTIR(I),TOTIR(I),I
      GO TO 100
  501 CONTINUE
C
C          FORMAT STATEMENTS
C
  800 FORMAT(1H1,/)
  801 FORMAT(A6,4X,I4,F6.1,I5,10X,I5,5X,I5)
  802 FORMAT(A6,A5,15X,I3,18X,2F8.1,51X,I7,21X,I7,54X,I13,21X,A10,F9.2,
     1     F9.4,2X,A2,A3,11X,3F3.2,F9.2,10X,I6)
  803 FORMAT(45X,43HIMPROVED RELIABILITY PREFERRED SPARES CANDIDATES//)
  805 FORMAT(80X,4HUNIT,5X,4HMEAN/11X,4HWORK,6X,6HMASTER,7X,6HMASTER,
     1     12X,5HCOST/,5X,7HPERCENT,4X,6HPER-,2X,6HREPAIR,2X,8HCALENDAR,
     2     2X,13HGROSS SAVINGS,3X,4HUNIT,6X,5HINDEX/11X,4HUNIT,6X,
     3     5HSTOCK,9X,5HSTOCK,5X,6HANNUAL,2X,6HDEMAND,1X,9HCONDEMNED,3X,
     4     4HCENT,3X,4HCOST,3X,8HYEAR BTW,5X,4H(K$),4X,5HPRICE,15X,3HREP,
     5     /1X,8HAIRCRAFT,2X,4HCODE,6X,6HNUMBER,7X,4HNOUN,6X,6HDEMAND,3X,
     6     3H($),4X,4HBASE,2X,5HDEPOT,2X,4HNRTS,4X,3H($),4X,7HREPLACE,3X,
     7     4HS YR,3X,4HLIFE,5X,3H($),3X,4HS YR,3X,4HLIFE,2X,3HPOL//)
  806 FORMAT(2X,A6,2X,A5,2X,I13,2X,A10,2X,A2,2X,A3,2X,F5.0,2X,F6.0,3X,
     1     F5.0,1X,F7.0,1X,F8.3,2X,F7.2,1X,F7.0,1X,F4.0,2(1X,F6.1),2X,I1)
  807 FORMAT(A6,A5,I13,A10,A2,A3,F7.0,2F9.0,F9.0,
     1     F10.3,2F9.3,F10.0,2F8.1,I1)
  900 FORMAT(61X,4HCOST,5X,4HUNIT)
  901 FORMAT(11X,4HWORK,6X,6HMASTER,7X,6HMASTER,21X,3HPER,5X,6HREPAIR,
     1     3X,4HUNIT,5X,4HTIME,7X,17HGROSS SAVINGS EST,8X,5HINDEX)
  902 FORMAT(11X,4HUNIT,6X,5HSTOCK,8X,5HSTOCK,4X,8HITEM MGR,2X,6HANNUAL,
     1     2X,6HDEMAND,3X,4HCOST,4X,5HPRICE,2X,8HCONSTANT,5X,
     2     17HREMAIN LIFE  (K$),18X,3HREP)
  903 FORMAT(1X,14HAIRCRAFT  CODE,6X,6HNUMBER,7X,4HNOUN,5X,8HALC CODE,
     1     2X,6HDEMAND,3X,3H($),6X,3H($),5X,3H($),5X,4H(YR),5X,5HAVAIL,
     2     2X,7HSUPPORT,3X,5HTOTAL,3X,3HSUP,4X,3HTOT,2X,3HPOL)
      CALL EXIT
      END
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